A Study on Innovation in Product Design Considering Aesthetics and Ergonomics

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BY

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dedicated
to
my
parents

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CERTIFICATE

This is to certify that the thesis titled "**A Study on innovation in Product Design considering Aesthetics and Ergonomics**" being submitted by **Bighna Kalyan Nayak** for the award of the degree of Master of Technology (Research) in Industrial Design Department of NIT Rourkela is a record of bonafide research work carried out by him under my supervision and guidance. He has worked for more than two years on the problem at the Industrial Design Department, National Institute of Technology, Rourkela and thus has reached the standard fulfilling the requirements and regulations relating to the degree. The contents of this thesis, in full or part, have not been submitted to any other university or institution for the award of any degree or diploma.

(**Dr. B. B. Biswal**)

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Bighna Kalyan Nayak

Abstract

Ergonomics based design offers safe, comfortable and efficient products by considering human aspects. Ergonomically designed products prevent fatigue and discomfort. On the other hand, aesthetics as a link between a product and the user's emotion contributes to obtaining more desirable products for the user. To develop products with aesthetic and ergonomic benefits, multiple factors must be considered simultaneously.

The literature presents the strategic focus on product design, arguing that the aesthetics and ergonomics dimensions may help a product to be a commercial success. The designer's decision-making in the concept design stage has a significant impact in the success of the product. Therefore, parametric and generative design become suitable approaches in the design process. Additionally this thesis presents a hybrid methodology to be adopted in concept design stage. This methodology will also utilise a parametric design algorithm.

This proposed research work aims towards a multi-criteria algorithm to assist the designer in the concept design phase to come up with better product design considering aesthetic and ergonomic criteria. The fundamental contribution of the algorithm lies in its focus on multi-criteria analysis and its ability to include new factors in the evaluation of possible solutions. Aesthetic and ergonomic concepts like golden ratio, form, colour, texture, gender and anthropometry composed these multi criteria. To develop this new methodology a thorough literature review was used. The purpose of this study is to find product evaluation methods considering aesthetics and ergonomics and does not consider public surveys for evaluation. Problems in the aesthetic evaluation are discussed later in the work.

A case study is used to validate this design methodology. Finally, the aesthetics and ergonomic elements were modified by using Grasshopper software as a graphical algorithm editor. The results indicate a need for reliable objective evaluation methods. As a consequence of the study, suggestions for improving and applying existing methods are proposed.

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Chapter1

INTRODUCTION

1.1 Overview

In this competitive market, a product should serve its primary purpose. Nowadays consumer demands are different from older times. The product has also become a status symbol for a consumer. Aesthetic appeal is equally important for a product to sustain in the market along with the functional appeal. But how can one differentiate between the aesthetic appeals of two similar categories of products? The answer lies in the comparative evaluation of the products using previously defined rules that guide evaluation. From this extensive research it's identified that from the flexibility and functionality perspective, one can evaluate a new class of product. But from the aesthetics, usability and ergonomics perspective, it's difficult to evaluate a product as per design standards.

From the studied literature, one concept that can be derived is that as per product's aesthetics, it's difficult to evaluate product's beauty. There are a lot of constraint like age, sex, culture, time of the process that cannot be avoided or ignored. Developing and poor countries often don't have enough resources to spend on design processes, and therefore apart from functionality properties like aesthetics, ergonomics and usability are ignored.

Implementing aesthetics and evaluating it in a product, is a confusing and blurred process. Currently, design and evaluation methods involve the experience of the designer and public surveys because there are no fixed rules in design. (e.g. Newton's law in science). The solution of this above discussed problem might lead to classification and standardisation of design. Though it will take the time to have changes of this nature, until that time artificial intelligence in the field of design by this algorithm is concluded as a better option.

Perhaps a small story will summarise the development and origin of products with its relevance to industrial design. During evolution, long time before mankind developed household appliances to carry out day to day activity, even before the first kind of scripts and languages came into existence. For different products aesthetics, ergonomics, usability and functionality values are different. For example, if the product is an art piece, product functionality and usability can be aesthetics itself. Similarly, for a robot design, functionality comes as a priority than aesthetics and usability. With substantial competition in the market, companies prefer to launch a variety of products with equal functionality. Previously this trend was motivated by functional requirements (Cillo et al. 2008).

Imagine a robot and a showpiece having the same level of aesthetics and functional values implemented during design, provide a chance for a common platform for design evaluation. In some cases functionality and aesthetics may have conflicting interests; material optimisation is a clear example of it. On the basis of the origin and the nature of working, differences and evolution between engineering and design solutions are explained through Figure 1.1.

A long time before human race identified their dependence on water. To store and transfer water they need to find a solution. They discovered, apart from hand they can also transfer water with small naturally available bowls. And later one day an engineer invented clay pot to store and transport water. Gradually the size of the pot started to increase, as per their need of water till the day the pot with water got too heavy to transfer.

A designer came up with a solution. He attached handles and gave shape to carry the pot comfortably with a curve. That curve was inspired from the waist of a female as during that time women did the work of transferring water. He modified its form and structure according to the figure of the women. The new modified shape fits perfectly on the waist of women. In this way, human race overcame the difficulty in transferring and storing water.

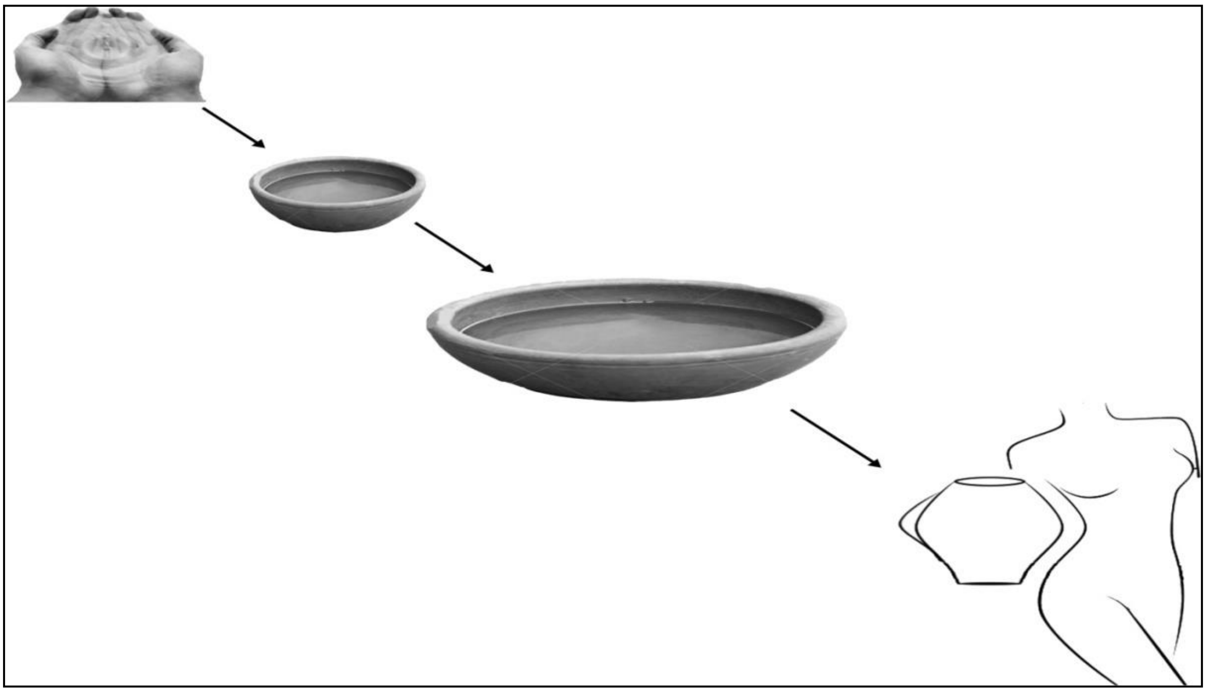


Figure 1.1 Existence of design and innovation through evolution

Moral of the story is that Industrial design has a strong and deep influence on the existence of human race. The work of Leonardo da Vinci's can be presented as an example in Figure 1.2. During that time engineering and design had a combined role. But the effort of creating diversity made it worse, which ended in creating a distance between engineering and design or between human satisfaction and human need. Comparing with old times, this research work concludes that the reason for the reduction in innovation and its application might be directly linked to the distance between design and engineering. Particularly in the poor and developed country, this distance is more. In India too, this problem exists. The reason might be, giving less importance to arts nowadays, as the result of it writer, poets, artist, musician and similar profession are in danger. This kind of situation might lead to a lack of cultural essence in product design that can result in a lack of aesthetics in new product development. To achieve a rich design diversified society, like in movies (e.g. Star Wars, Lord of the Ring, etc.), designers have to raise and establish some design rules. These hold the cultural significance for the mankind that mankind had earlier once (e.g. ancient Indian art).

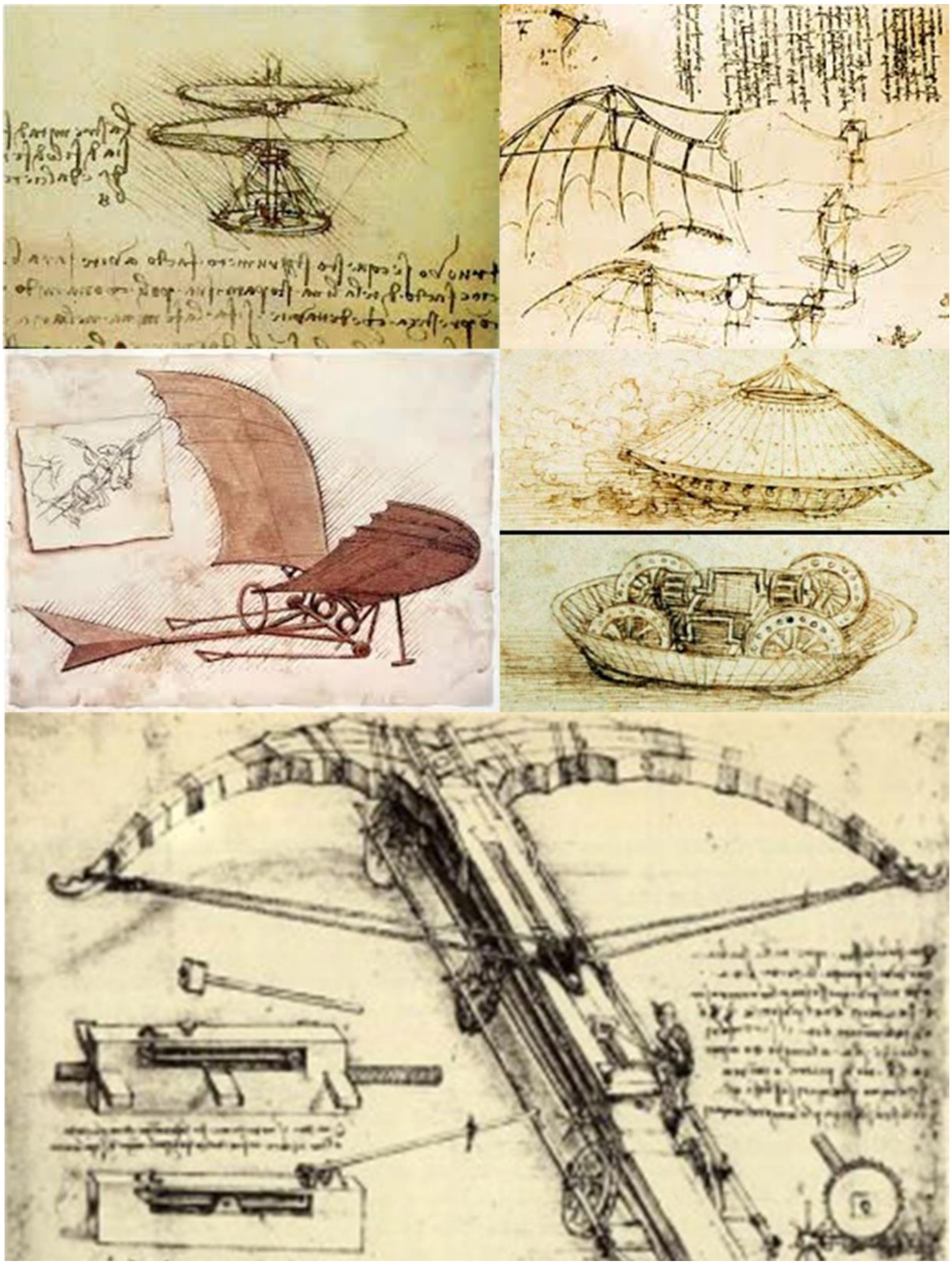


Figure 1.2 Works of Leonardo da Vinci with design and engineering

During this study, graphics design, rules were identified and segregated. The primary differences and similarity between graphic design and product design were determined. The similarity of design theories leads to the identification of basic and most common design rules like (Golden ratio, Gestalt theory, some colour theories, etc.), with a common aim to make things beautiful. To evaluate product’s beauty is difficult, particularly with so many different standards available in the market. When the whole world runs on standardisation, the question that lies ahead is how to quantify beauty?

Most of the design standards depend on design evaluations. Design evaluations are the direct result of public surveys. The question arises that why the beauty standards of products vary with time, sex, place, cultures and personality. People's evaluations of beauty are their own psychological evaluations and are unreliable and unstable along with many constraints.

Some general problem found in surveys:

- The design includes a broad topic and survey sometimes become too large and difficult to focus on specific problems and issues.
- The data could lack in details or depth on the subject being investigated.
- It is almost impossible to control and maintain the response conditions of all participants.
- The results may be generalised outside the group of people who participated in the survey.

Therefore, while searching for a related problem with common philosophy, one software (Grasshopper) was identified in the branch of architecture. That is used for parametric modelling, generative design, optimisation and simulation. Grasshopper is a graphical algorithm editor integrated with Rhinoceros (CAD software) 3-D modelling tools. Unlike Rhino Script, Grasshopper requires no knowledge of programming or scripting, but still allows designers to build form generators from simple ideas.

This design approach is primarily different from conventional CAD simulation processes. Traditional simulation has not become an excellent tool in the conceptual stage of design because these tools are only able to simulate and evaluate the performance of the geometry. Therefore, most of the traditional simulation tools are not parametric.

From the Figure 1.3 it can be seen that in Grasshopper, geometry can be created by dragging and dropping available components. These elements represent data or functions in working. These components can also set up relationships between geometries. Grasshopper consists of two main types of objects, "parameters" and "components". Parameters are used as input variables to feed into components. After processing the variable and component transform into output or results. In Grasshopper, inputs may be geometry or a single data. However, Grasshopper allows designers to connect directly a generative model with simulation.

Therefore, the change of parameters in the parametric model automatically affected the simulation outcomes.

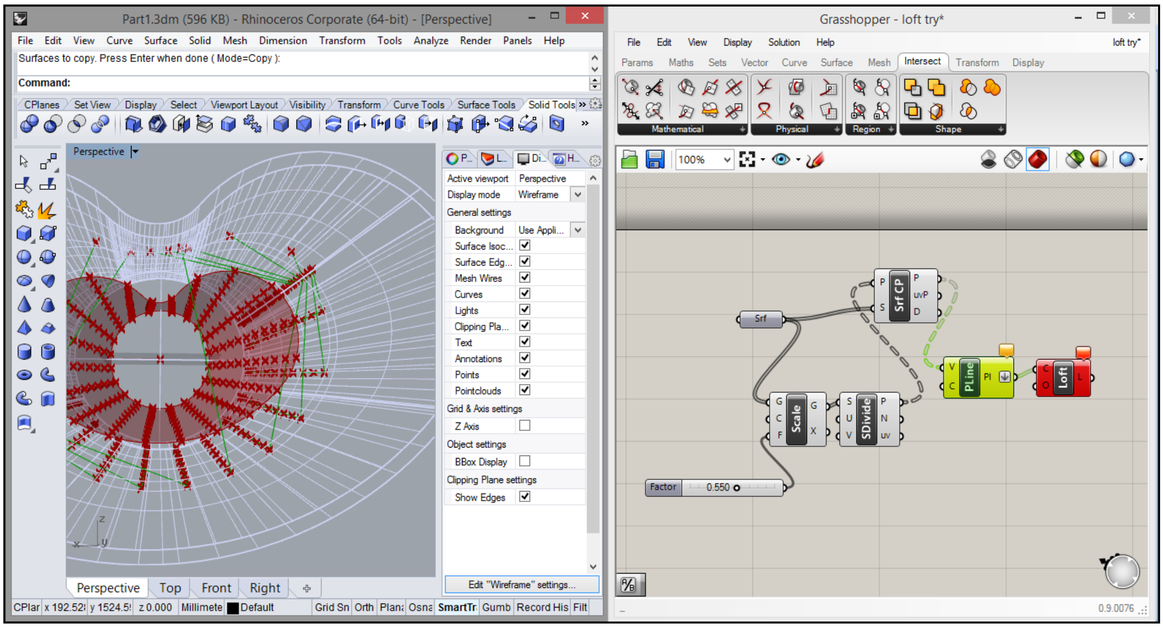


Figure 1.3 Example of Grasshopper working with Rhinoceros 3D modelling software

The prospects of product design for companies means of achieving an ambitious advantage in market survival strategy. Some studies have revealed that a company's design potential has a direct impact on its success rate (Hertenstein et al. 2005). This inspires introducing a unique design strategy by the company management.

Product design is a problem-solving activity, whose purpose is to develop a successful product fulfilling consumer's needs. To achieve this goal, some methods have been used by designers to obtain an optimal solution, through the process of data collection, analysis, synthesis and decision making. Today product development process is facing rapid, and continuous changes in the market. A well-designed product, should not only satisfy consumer's physical requirements but should also meet their psychological needs. During the process of defining suitable design solutions, a designer has to consider a broad range of influential factors. Aesthetics and ergonomics indeed are the most complex ones. Only an appropriate equilibrium of these factors leads to optimal product design.

The industrial design attempts to enhance the quality of life by designing products that meet consumer requirements. Combining concepts from various fields, including design, computer technology, aesthetics and ergonomics, industrial designers seek to improve the quality of life by developing products that would meet consumer needs. Industrial designers focus on customers' perceptions of products and their preferences for certain shapes, textures, colours, styles, prices and functions. Because new products are continuously being released, manufacturers must continually design products to satisfy customer needs, in order to be competitive. To avoid this companies are also trying to differentiate their products to create recognition through unique product appearance. It's very similar to branding but in a designerly way.

Companies with highly-skilled designers have more ideas, better and more competitive products and shorter production times than companies with average designers. Product design is gaining a lot of attention within and outside industries. There are numerous well-known examples of companies with a diversified design point of view. The base of their business success is on their capability to continuously develop products, using innovative product design in terms of the product's aesthetics, ergonomics, usability, functionality, etc.

1.2 Importance of aesthetics and ergonomics in product design

Today product design is an interdisciplinary job. This makes the development process more complicated. There are different categories of design approaches such as engineering design, industrial design, design for manufacturing, design as per usability, aesthetic design, ergonomic design, etc. While designing a product, it's hard to address all these design concerns in a single product. That's why, in most of the products the aesthetics and ergonomics design categories are not included, or they are not given enough importance. The adverse effect of this incomplete design process is the failure of the product or in the product not performing well. The product has to be accepted by the society both physically and psychologically.

This work also aims to find out the solution for the above-explained problem. This research work is motivated by "deconstruction design" philosophy, which teaches to raise the question on everything, the product working, manufacturing, looks, ergonomics, usability, etc. This will result in a hybrid design effect providing a solution of the current design problem. The main purpose is to draw out the true essence of the product.

Below described literature will present the importance of product design, with the opinion of several authors simultaneously discussing elements of aesthetics and ergonomics in products. This might help a product design process commercially as well as socially. Good design is essential in new product development as functional, visually and ergonomically attractive products can be clearly differentiated from the competition. Designers usually have clear expectations of what they think needs to be incorporated into new products. However, it is not always easy to integrate design requirements into actual complete product design because the need conflicts with commercial interests. So the aims of designers may be somewhat compromised in the race to market. Without aesthetics and ergonomic inclusion, there won't be any diversity in design. Without diversity, there won't be any evolution. The product will appear dull and unfriendly to users. The level of aesthetic and ergonomic transformation to design in most of the cases depends upon designer's experience. Thus the emotional and semiotic references of products in product design are progressively more relevant to consumer product choice.

However, the development of new products using aesthetics and ergonomics is complicated and may also lead to some methodological changes with managerial challenges. While focusing on artistic values and aesthetics implementation, new product development goes through lots of conflict between commercial and creative interests (Smith et al. 2011). An example is material optimisation.

There are several theories and approaches to product design. Some say product design should strictly lead by customer need and often say creative ways should do it. The reason might be the vast variety of products. Artistic products cannot work on existing market systems. So it is assumed that, for these kinds of products, design procedure should not be viewed in the perspective of commercial interests. It's also difficult to control and maintain the level of creativity in design works. In other words "It's difficult to quantify beauty."

1.3 Relevance of research with purpose

From the above study, it's identified that, due to increased interest in product design. Industries have started to consider aesthetics and ergonomics as a strategic design tool. But the spotlight on aesthetic and ergonomic requirements is a challenging process during the development of new products. Due to design's multidisciplinary span, it's difficult to establish a balance between commercial and creative interests.

Based on the above background, the purpose of this Master's thesis is to describe and analyse the importance of aesthetics and ergonomics, with implications of it in design methodology. In this research, a broad study is done in perspective of design methodology. The Methodology can be defined as product development process, which incorporates aesthetics and ergonomics as important dimensions. The reason for selecting this problem is that the previously mentioned challenges in product development process are difficult to address in the industrial development of products.

The focus will be on the critical, initial phases of newly suggested product development methodology. The challenges described above form the focus of this Master thesis as the primary research effort. In addition, further analysis needs to be done, to automate the concept design phase and to transfer topological values with the help of an algorithm considering commercial and creative interests.

1.4 Research Motivation

Current engineering designs without aesthetic and ergonomic considerations are failing to reach customer satisfaction. In certain cases, designers are considering to reach the customer need but most of designer decisions are based on their intuitive judgements, assumptions, experiences, inspirations, etc. The existing methods for using and studying aesthetics and ergonomics in product evaluations are often highly specific to context, and require both subjective and objective inputs.

The preliminary need of a design for customer satisfaction by considering principles of ergonomics with the psychological need for aesthetics are driven towards the development of novel methods. This research work aims to resolve this problem and reduce the gap between physical and psychological needs of the customer by defining a design methodology for ergonomics and aesthetic design considerations.

1.5 Broad research objective

After an extensive study of the subject under focus and collecting information from the related researchers, peers and users, the current research project envisages the following as its primary objectives.

- To identify and address current design problems of poor and developing nations
- To consider aesthetics and ergonomics modules in concept design phase apart from functionality and usability concerns
- To develop a methodological model during concept design phase to transform topological values for implementing aesthetics
- To investigate the current aesthetic and ergonomic evaluation process and to find the problem behind its implication
- To automate the concept design phase with a case study considering aesthetic and ergonomics
- To reduce the gap between engineering and design

1.6 Methodology

Nowadays most of the products are modified versions of the old and existing products. For that reason, adaptive design models are famous in the field of design. Clarkson et al. (2005) specified that part of the design process is fixed from the start. The design process deals with concept design, details design and manufacturing phase. Our problem revolves around concept designing phase where during the topological transformation of ideas, design methodologies ignore other aspects of design.

The developed algorithm helps to generate concept design of the product by applying aesthetics and ergonomics following basic design rules and anthropometric data. Modification in concept design phase becomes very easy, less time consuming. This research tries to find a semi-automatic way to integrate ergonomics and aesthetics in concept design phase with different design outcomes. In this process trial and error, approaches are made with mathematical definitions, based on simulation feedback.

Anthropometric data have a significant role in the usability of the product, which lead the success of the product. But aesthetics cannot be ignored because the role of aesthetics is silent but the effectiveness is very high. The main reason for aesthetic success is the capability to influence user's psychology. Also, the role of product success is directly related to the combined influence of functionality, aesthetics, ergonomics and usability. As per current design process, these factors are variable and survey dependent. But the automation, in the field of concept design can revolutionise the current design process. The algorithm affects the above-explained design by influencing characteristics and improving by suggesting the model. The most important thing it generates is the solid CAD model from an image.

Today, the requirements in the product performances lead to the creation of solutions. That solution allows to outline approaches and perform simulations; that permit the designer to assess the performance of outputs in digital design. Here performance means the overall design process, which includes functionality, aesthetics, ergonomics and usability. Ergonomics and aesthetics are given special attention due to the ignorance about them in current and conventional design processes.

Despite the extensive research in recent history, no single model can be agreed to provide a satisfactory description of the design process. In this chapter, some modern approaches to the design process are presented, and their practical relevance is discussed. A hybrid model is obtained from the classification discussed. Furthermore, a developed algorithm is applied to bring automation in the concept development phase. Throughout the chapter, a design methodological classification is done while discussing the development of the algorithm to be implemented in the new model.

1.7 Problems in classifying models of designing

Design is a well-known, ill-structured and head scratching problem. It is hard to describe the design process satisfactorily, and it is an equally challenging task to define the relationships between models concerned with its various aspects. Frameworks seem diverse and difficult to relate to the models they describe.

Clarkson et al. (2005) classified and highlighted the design process by stage vs. activity-based models, problem vs. solution-oriented literature and abstract vs. analytical vs. procedural approaches. Furthermore, they clarify how abstract, stage and activity model approaches are helpful to develop concept design phase easily compared to more sophisticated approaches to project-based and procedural methods.

The majority of the outlined models of design are firmly focused on technical features for solving design difficulties. Some of the models are simple in nature and have been applied to many design sections. The general form of Evans' spiral model is still in use after more than four decades in a lot of fields from ship design computer software design. The product structure-based design approach is not considered due to its irrelevance to the aim and motivation of problem statement.

As with models, methods may be dependent or independent of discipline; whereas morphological combination is of limited use in the design of non-mechanical products like microprocessors, brainstorming and requirements analysis are applicable in most situations. According to Pugh et al. (1990), successful product design is subject to the integration of such general design methods with traditional engineering expertise. In practice, the applicability of such models and approaches are limited by their product-focused perspective, which implies that the fundamental difficulty in a design project lies in finding solutions to the technical problems. In reality, however, even the simplest design process is a highly complex socio-technical activity requiring a much broader range of skills, from marketing to human resource management.

Hsiao et.al (2008) performed experiments whose results can be used for colour planning in product design. They derived the relationships among the product image, colour area and aesthetic measurement of the product. The pixels of an area of colour are used to obtain the proportionate relationship between different coloured areas in a given solid visual angle.

Based on the link between the Hue, Value, Chroma and coloured area proposed by Munsell, other factors are integrated to set up one formula for evaluating the aesthetic degree of colour matching. Aesthetic measurement is considered to be influenced by the colour environments, colour areas, component colours and display angles of the product. The colour planning for developing a cell phone was performed based on this model.

Furthermore, many authors describe how most complex design projects place substantial limitations on early concept design, with constraints such as existing product platforms and legislative requirements often predetermining the form of the solution (Pugh et al. (1990)). In such circumstances, many concept design methods are of limited use, and the primary difficulty design companies face lies in the integration of diverse methods, disciplines, tools and personnel.

1.8 Aesthetics and ergonomics combined methodology

Figure 1.4 below presents a methodological framework on the ontology of aesthetic and ergonomic factors regarding product design, with the emphasis on design automation in concept design phase. In the process of defining suitable design solutions, the designer has to consider a broad range of influential factors. Aesthetics and ergonomics indeed belong to the more complex ones. Less experienced designers could encounter several problems during this design stage. Although some literature can be found in industrial aesthetics and the aesthetic design of consumer goods. The designer still has to have amassed quite a lot of experience and knowledge in the field of aesthetics, to choose and carry out appropriate design and redesign actions for improving the aesthetic value of the product within a reasonable time. On the other hand, the ergonomics of a product, especially product to be manipulated with upper extremities, is also very significant. Only an appropriate equilibration of these factors leads to optimal product design.

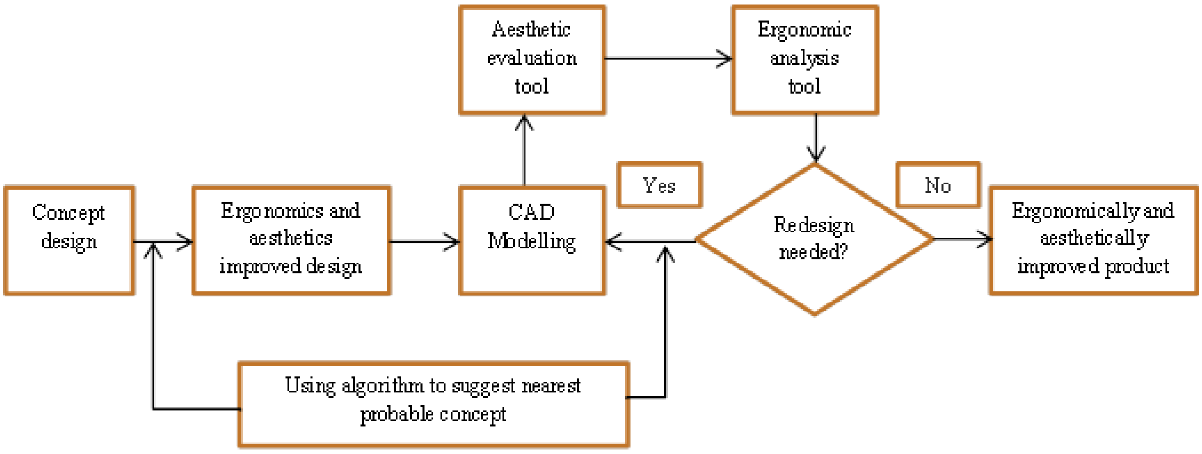


Figure.1.4 Application of the new methodology to apply the developed algorithm

From the Figure 1.4 it can easily identify how concept design phase of a product can be modified and automated through an algorithm. After a concept being selected it is processed through CAD modelling to digitise the model. Then the selected model passes through aesthetic and ergonomics evaluation tool. In general, aesthetic evaluation is done by public surveys. But some of the evaluation processes of ergonomic designs are data based. From there some idea about the designed product can be captured.

On the other hand, the primary aim of this research work is to avoid the public psychological evaluation of the designed product for its unreliability. And the reasons of its unreliability are explained in previous chapters. To overcome this problem, the efforts have been made to develop an algorithm, which partially automates the concept design stage. And at the output, it generates an improved model of concept considering aesthetics and ergonomics.

The conventional design model can be used to provide feedback for iterative design modifications often changes of the model can be spontaneously achieved by generative processes controlled by the analytical and numerical outcomes.

1.9 Expected outcome

In this work, the investigation is done to include aesthetics and ergonomics in the current design process by studying the principles, and functions of design/art, and extends its use in the field of product design. Based on the study of literature reviews, this research work must be able to utilise and evaluate the application of ergonomics and aesthetics with the help of a tool in the current design process. This requires an interdisciplinary research approach. Expected tool should be able to relate and use theories and methods of ergonomics and aesthetics.

The basic assumption is that the developed tool can help in reducing the dependency of the user evaluation in design evaluation process, and will be a part of decision-making in concept design phase to transfer the topological interests in the developing model. Additionally, is expected that the new hybrid methodology of including aesthetic and ergonomics will lead to developing a new algorithm that later on will be applied to prototyping new products.

The expected algorithm can be viewed as a solution to the practical problem of user psychological evaluation of the product. Furthermore, the algorithm will be an aid to designers as a tool in the concept design phase.

1.10 Organisation of thesis

Five chapters presented in this thesis are organised as follows:

Chapter 1: Introduction

Chapter one describes this topic, that introduces the research questions with explanation with significance. The importance of the methodological model of concept design phase is correspondingly shown. This chapter also justifies the reason and selection of this topic.

Chapter 2: Research frame and previous research

This chapter identifies and explains the key debates in product design, which includes theories and ideas of researchers in the field of aesthetics and ergonomics and implementing it in the field of product design. Furthermore, these ideas are evaluated and flaws are identified and arguments are presented to analyses the assumption of other researchers.

Chapter 3: Materials and methodology

In this chapter growth and development of the algorithm is presented. The algorithm is written in Grasshopper design modules that run on Rhinoceros software. The main purpose of this algorithm is to implement aesthetic properties and ergonomic anthropometric data to obtain a proximate suggested model so that user evaluation can be avoided, a step taken to standardise design.

Chapter 4: Design modification of the bottle using ergonomic data

This research work presents a multi-criteria algorithm to integrate aesthetics and ergonomics in product design. The algorithm has been developed in Grasshopper, a graphical algorithm editor integrated with Rhinoceros 3-D modelling tools. In the process of generating product alternatives, the proposed algorithm considers multi-criteria such as golden ratio, colour, form, anthropometric data, texture and male and female preferences.

Chapter 5: Result and discussion

In this section, the propagated result is discussed with a comparison of different models. Those models are modified by variation in the geometrical elements in the algorithm. And an analysis is done with application of aesthetics and ergonomics.

Chapter 6: Conclusion and future work

This chapter concludes the thesis and projects the understanding of the current implication of aesthetic and ergonomics in concept design. Furthermore, it notes the key themes and limitations of the current research work. It is expected that from this new design process there will be automation in the phase of concept design. In future work, design evaluations will be conducted in more open and correct ways. Recent developments in algorithms and computer programme might lead to artificial intelligence being used in the field of product design and might result in standardisation in the area of design.

1.11 Summary

In the current chapter, the overall outline of the different types of design concepts, histories of evolutions of design and objective of the research are presented. Apart from the identification of various design methodologies, the importance and implication details of aesthetics and ergonomics are discussed. Finally, a hybrid method is suggested to accommodate these factors in the current design process. The organisation of thesis is also presented.

Chapter2

LITERATURE REVIEW

2.1 Overview

This part of the thesis is presenting theories behind the study. The part has been written with a brief literature review of books, journals, articles, in which the principal function is to identify the key points and direction in the existing research framework. It again concerns with theories and ideas and the evaluation of above theories; assumption and argument presented regarding aesthetic and ergonomic considerations in the field of design.

2.2 Literature survey

Nowadays product design is at a whole new level. Several studies revealed (Tractinsky et al. (2000), Mahlke et al. (2007)) how aesthetics, ergonomics, usability and functionality motivates user satisfaction. All these above factors depend upon the first impression of the customer on the product. In addition, to influencing the first impression of the product, aesthetics and ergonomics should be included with more detailed design decisions.

A product is always recognised by its functions. Because the primary purpose of the product is to deliver the reason, it's designed for. Although there are additional factors, present in appearance like usability, aesthetics, ergonomics, etc. The process of concept design phase is a complex part of product development process. Utterback et al. (2006), define the difference and inter lapping between product function and product form. Product's form directly affects the product functionality and vice versa. The product form is a part of product aesthetics.

Nowadays design has a lot of dimensions due to massive commercialization and competition. Perfection in the design process led to a broader and refined overall process considering all aspects of design. It mainly depends on the targeted customers, product type, product interaction, etc. The differentiated working areas and responsibility between an engineer and designer are defined earlier. Which later on (Utterback et al. (2006)) defined as functionality by separating engineering, design with artistic inputs on the basis of their different functions in the design process to create and convey a meaningful message in design.

Among all these possible interpretations of the design during concept design phase, this Master thesis mainly focuses on the aesthetics and ergonomics aspects of design. i.e. on the development of a product's form and visual appearance rather than its function.

2.3 Most Relevant Literatures

Particularly during the concept designing phase, product aesthetics is incorporated in product design. As per Wucies (1972) in his book "design language is the base of design creation. It has no apparent law. Each design theorist may have an entirely different set of discoveries. A designer can work without conscious knowledge of any of these laws, principle, rules or concepts because physical and emotional state differs from person to person with time, age, culture, etc., but understanding and applying them would undoubtedly enhance his as well products capacity in real world application." By following current design process K Mallikarjnn et al. explained the generic product design procedure for a cycle including aesthetic and ergonomic considerations. But during typological transformation in concept design phase, it didn't explain the procedure or methodology to extract aesthetic characteristic of the product.

Demirbilek et al. (2003) found answers to communicate to users at emotional level by raising questions about how to design products triggers 'happiness' in one's mind; which product attributes help to the communication of positive emotions; and finally, how to evoke such emotions through a product. Ross et al. (2010) recommended some design factors and apply them in an intelligent framework based on the ontology of aesthetic and ergonomic factors regarding product design. Furthermore, they also developed a concept of interactive product design, that they derived from aesthetics based on Pragmatist philosophy and translated it into a design approach. They make it possible by studying the interactive product behaviour.

Tomiyama et al. (2009) successfully classify the available design theories focusing on industrial and educational use. They discuss this gap between practical and educational usages. Considering theories and methodologies based on ''math-based methods'', ''methodologies to achieve concrete design goals'' and ''process methodologies''.

This research (Ross et al. (2010)) provides knowledge of how the appearance attributes can be identified and what consumers see in durable product appearance. As a result appearance attributes perceived by consumers in a product can help a designer to transfer that quality to the product. They discuss the results of tests using specially prepared samples of leather by an interdisciplinary research approach. Participants were asked to perceive the texture of the samples via senses such as vision, touch, or a combination of both visions, contact through the blindfold, sighted smell test and a visual colour assessment test.

A fuzzy decision-making method is proposed to design a juicer by optimising various design alternatives. This study (Hsiao et al. (2008)) suggests a methodological model for a case study of a coffee machine that conforms to the psychological preferences of consumers by applying a genetic algorithm. Aesthetics measurement evaluation method were conducted with the area ratios and the colour. Also, the design of a mobile phone is proposed based on the relationship between the Hue, Value, Chroma and the coloured area suggested by Munsell colour circle.

2.4 Detailed Review With Categories

In this thesis, aesthetics and ergonomics implications are considered to develop a new methodology. Therefore, this part of the chapter provides directional guidance to the literature review. The following literature review is classified into three categories of deconstruction design, aesthetic and ergonomics.

2.4.1 Deconstruction Design

Philosopher Jacques Derrida introduced the term deconstruction in his book Of Grammatology in around 1970. Later on, when the book got translated into English, it got very popular in the fields of architecture, fashion and graphic design. Now, it recently put its foot in the field of product design. This research work will project deconstruction philosophy, from a design point of view.

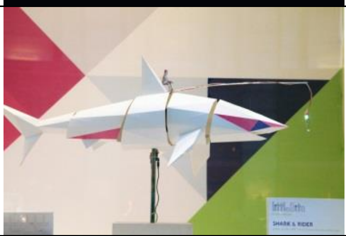
Asper(http://visiblelanguagejournal.com/articles/article/356/, https://www.typotheque.com/articles/deconstruction_and_graphic_design_history_meets_theory) "Deconstruction is not a style or 'attitude' but rather a mode of questioning through, about the technologies, formal devices, social institutions, and founding metaphors of representation. Deconstruction belongs to both history and theory. It is embedded in recent visual and academic culture, but it describes a strategy of critical form-making that is performed across a range of artefacts and practices, both historical and contemporary.” If these lines are interpreted into the design, then that would raise questions on every aspect of conception. It is the theory that later on brought revolution in the field of graphic design and graffiti works. Apart from functionality, product design started to consider other aspects of designs like usability, aesthetics, ergonomics, etc. A different perspective also opened in the field of eco-friendly design.

Derrida was a French poststructuralist the word “Deconstruction” had served to label architecture, graphic design, products. Derrida’s essay looks at the reception and use of deconstruction in the recent history of graphic design, where it has become the tag for another period’s style. Today this design trend has shown its trend in product design. In Table 2.1 some example of deconstruction philosophy has shown, that are applied on the field product design.

Recently a national conference “Design for India” (http://humanproject.in/design-for-india-deconstructing-design-workshop-mhrd/) in India discussed the problems in design sector in India. As a developing country of the large population leads to a shortage of supply of product range and money always these are significant factors for the growing economy. This leads to adaptation of incomplete design procedures, just to avoid the time and lose money. The problem comes with a range of products designed for only functionality. The native used to call it “jugaard”. This later on enhances the complications and leads to safety compromises, ergonomic problems and non-ethical designs, etc. Most of the poor and developing countries have the same problems.

Table 2.1 Deconstruction theory and its application to product design

Sl No.	**Product Images**	**Name and Product class**	**Deconstruction Description**
1		Dansk stole by James Killinger furniture	….
2		Fusillo by Marco Goffi furniture	Facilitate social interaction and conversation in public spaces. Flexuous and fluid inspiration.

3		Floating side table by Urban case Furniture	A floating side table that could be installed at any height to accommodate various bed and sofa designs.
4		Simple human sensor mirror	An improvement upon the existing vanity mirror.
5		Foscarini's concrete Aplomb Pendant Lamp	Aplomb also means "self-possessed" and "confident". Plumb-bob tool traditionally used by masons.
6		Little bits at Moma design store, Soho	A mixture of art and robotics. Inspired by drawing a man over a giant shark.
7		Folditure makes its leaf chair	Leaf chair is the world's thinnest folding dining height chair and it folds flat to less than 3/4 of an inch thick.
8		Sphere from scrap wood	Make you feel like you're looking down at a city from an aeroplane window.
9		Seer table by Matthew Bridges design	A square base with four triangular leaves that form a square when closed together, and then open out to form a larger square.
10		Bec Brittain's vise light	Double-fade glass globe that mimics a sunset and situates it within a brass, spider is hanging from a thread.

11		Eau good water bottle by black + blum	Incorporates active charcoal to purify the water so that people can use normal tap water to drink. To inspire people to stop buying water bottles.
12		D-Build Deconstruction tool design	Portability and comfort considering core user needs. Mechanical advantage is enhanced by 10%.
13		Cocoon by Mans Salomonsen	Encourage and inspire people to use more fresh groceries. Design is inspired from hanging nest of birds

2.4.2 Aesthetics studies and its evaluation

As discussed in above literature, designed products should have a high degree of aesthetic value over their utility. Thus, the designers not only need skills to design as per functionality but also need skills to create artistic value to the subject. Aesthetic value creation is often seen as related to artistic production. However, the literature sometimes also seeks to separate the designer from the artist. For example, designers are connected with industrial processes and have economic constraints. But at the same time, artists create something primarily in order to express their subjective conceptions of beauty, emotion, or some other aesthetic ideal.

Product design, where aesthetics is an essential element, demands designers with artistic skills (Utterback et al., 2006), and the sourcing of designers with such skills may be a challenge for companies that used to be driven by functional requirements.

Initialy a objective measurable of aesthetics design subjects are used that measured complexity, symmetry and balance. And later this process has been widely used in the design sector. Bertelsen et al. (2004) proposed a subjective approach based on questionnaires to evaluate visual aesthetics. Interfaces can embed choices, behaviour, languages, values, world views, and aesthetics into technical infrastructure.

Can aesthetics affect users to gain positive emotions and experience surprising positive outcomes (outstanding quality experiences)? These are the experiences that give an unexpected positive impact on the users. A system should correspond to user's expectations not to cause disappointment. But there may exist cases where the expectations can be exceeded positively, giving users a positive emotional rise. The new focus will be on positive psychological outcomes such as joy, fun and pride (Hassenzahl et al., 2004). In other studies, designers discuss how to design interfaces evoking specific emotions. In general, aesthetics deals with perception, cognition, cultural elements, semiotics and ethics. A product design, in terms of form, may provide the user with different benefits.

2.4.3 Ergonomic studies

In past, researchers have focused separately on aesthetic or ergonomics. Ergonomics and human factors researchers have made great contributions to the safety, productivity, ease-of-use and comfort of human-machine-environment systems. But aesthetics is largely ignored as a topic of systematic scientific research in human factors and ergonomics (Liu (2003)). However, considering ergonomics while considering aesthetics helps to realise the goal of real human centred design, creating designs that are more desirable and better for the user (Roberts et al. (2012)).

Ergonomics is not only used in the sector of product design, but it's also utilised in the field of job scheduling for preventive measures. Cuesta et al. (2012) explained the worker´s fatigue and muscular stress risks. The study showed the need to measure and evaluates risks to improve the efficiency in work and reduce the costs. Kaljun et al. (2012) presented a case study of the design of an actual chainsaw with emphasis on ergonomic design solutions that can be transformed into ergonomic design recommendations.

As many of the above interventions illustrate ergonomics offers, some benefits are excellent standard ground for labour and management collaboration, so that both can benefit. Managers can benefit regarding reduced costs, improved productivity and employees regarding improved safety, health, comfort, usability of tools, equipment, including software, and improved quality of work life.

Caiet al. (1998) implemented ergonomic anthropometric data to conduct an experiment on public squatting-type toilet design. A field survey in Taipei revealed that, newly designed squatting type public toilet satisfies better sanitary requirements. Hal W. Hendrick presented 23 valuable ‘‘lessons learned’’ regarding applying ergonomics to systems. The work also documented results from reported cases and presented it to validate each of these practical learning points.

Klutha et al. (2006) shown the need for safe ambulance cots, in a relative ergonomic study. During the comparative analysis of stretchers, performances are measured by carrying them on a staircase at normal speed, at increased speed, lifting of the stretcher and loading the ambulance cot into, as well as unloading it from, an ambulance. An ergonomic design moreover increases the safety and usability of the system during a rescue operation. Also due to the ergonomic design, the factors like effort applied, time spared, and muscular strain are improved which is very vital in saving life.

Wang et al. (2014) explained how people with physical disabilities find it difficult to obtain suitable clothing. This work leads to designing functional clothing considering ergonomic norms for wheelchair users to perform daily living activities. Factors like dressing and undressing, going to toilet and bathing were deemed important to obtain the user-friendly design.

There is no definitive research about benefits of integrating aesthetic and ergonomic factors in product design. However, there are some approaches to the problem as per Tractinsky et al. (2000), Ross et al. (2010), Roberts et al. (2012). Therefore, developing tools to enable designers to create and evaluate products prototypes quickly and flexibly taking into account aspects, that impose on aesthetic, and ergonomic criteria appear as a necessity to support the further demand of aesthetic and ergonomic integration research in product design.

The area of ergonomics positively influences the value of the product, by improving human-product interaction. Good ergonomics practice takes human diversity into account while contributing to product development. Again, enhanced ergonomic considerations in product design can also lead to increased in human-product interaction. Later, this affects the quality of life in day to day work.

2.5 Gap in existing research works with problem statement

From the above literature review, it's concluded that the current design process lags in coordination between different important aspects of design like aesthetics, ergonomics, usability, etc. Though several design models are available, they lag in fulfilling user’s psychological and sociological needs. The reason might be awareness or burden on the current design process.

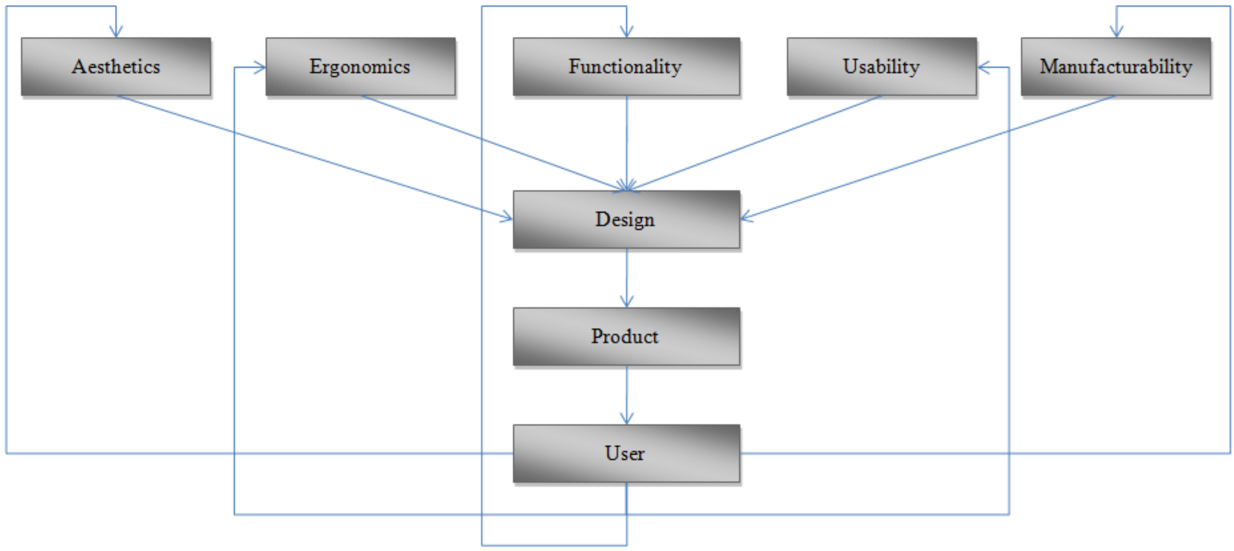


Figure 2.1 Hierarchical flow of design data

From figure 2.1 it can be seen that most of the design evaluation process depends on public evaluation and surveys. There are constraints; factors vary from person to person with age, sex, culture, time, place, personality, etc. No doubt the evaluation of a product by the user leads to some valuable breakthroughs in removing major design defects. But it still cannot be concluded as a valid input to the current design process, because it doesn't have any fixed output. For that reason, the result of design would have an unstable and unworthy effect on the product. Perhaps it is assumed that the whole evaluation process is just the replica of user's own psychological evaluation.

2.6 Summary

From the above literature survey, it is summarised that all these discussed procedures have one common flaw. The above-explained procedures and methodologies require direct or indirect psychologically evaluated data to obtain design results. The major problem is that subjective data from user surveys do not have a certain fixed effect, and the factors influencing the psychological data are many, like age, culture, mood, time, etc.

Chapter 3

MATERIALS AND METHODOLOGY

3.1 Overview

In this chapter, the methodology behind the design, as well as its relevance regarding the corresponding purpose of this Master's thesis, is presented and discussed. First, the choice of the subject with methodological research approach is discussed. Second, the progress, problems and the implication of aesthetic and ergonomic properties in the current methodology are presented and discussed. Last, the tools, the methodology to develop algorithm are discussed and evaluated for the credibility of this Master's thesis.

3.2 Problem statement

This research work aims to reduce the gap between the physical and psychological need of the customer by defining an algorithm to consider ergonomics and aesthetic in design. Different culture people's sizes, working habits, environments, use needs are different. So for a different culture, product design should be different. Though design considering aesthetic and, ergonomics has started but till date, it is not adopted worldwide. Still it's considered as a burden on product development in this competitive market, but the reality is different. There are several factors of this problem, like extra time required to develop a product, price of the product, the risk of launching a new design to market. But the major factor is the product not fulfilling the physical, sociological and psychological requirements. This is the current major problem of developing and poor nations.

Another major problem is that the user's psychological evaluations of designs are used as the input to refine the design solutions. The untrustworthiness of feedback data is due to its lack of stability. And not considering feedback data can lead to the additional risk of lack in innovation in new design outcomes. Furthermore, the major problem is the lack of education in the direction of art among design evaluating group.

3.3 Design tools used to develop algorithm

In this section, few tools will be explained that helped to develop the algorithm because the methodological procedures depend on the related tools. Like Parametric Modelling and simulation process.

3.3.1 Parametric modelling

From the name, it can be identified that parametric design is controlled by parameters and constraints by combined effects of different procedures. In the parametric design, the parameters of the particular design control the geometry and not the pre-defined shapes. Furthermore, different forms and geometrical configurations can be easily obtained by various parameter values (Kolarevic (2003)).

Parametric design improved the role of designers while designing a form from pre-defined rules. The designers often define these rules. The parametric design has started a new trend, which offers an easy and effective way for geometrical customization and form optimisation with higher flexibility in finding the solution space.

Parametric models have two components that are named as parameters (the geometric relations and numbers) and constraints (the fixed elements of geometry). Subsequently, the parametric approach requires assigned values for parameters, where the mathematical equations are capable of expressing connections between the parameters. Simulation and parametric models together offer a way to find the possible solutions by testing and selecting through parameter and constraints.

Essentially, the parametric design has a dynamic part in the current design process by characterising the geometry with distinctive parameters. In the long run, implemented parameters turn into a design tool that describes new design modifications.

3.3.2 Simulation

Simulation demonstrates a modelling procedure that can be utilised to imagine the execution of product, through the mental representation of essential parts without expressing the whole of it. The simulation methods and software depend on the potential of the system for modification. But the fundamental drawback of simulation processes is that they work under experimentation processes. It implies that the designer needs to find answers, keeping in mind the feedback details for the simulation model.

Simulation software have quickly developed in the recent years, acting as a connection between parametric design tools and simulations based designs. The outlined design procedure includes repetitive, evaluations and adjustments to get convincible outcomes. Regardless of its some disadvantages, simulation is considered a hugely affordable tool for digital modelling. Simulation helps the design process to identify weakness and helps in accomplishing the design solution.

To operate the simulation software, design data has to be uploaded to the operating software first. Before that, all the constants and factors have to be identified. Then, the modification is done in parametric design. It makes the changes and reconstructs it in simulating software. From there the overall design can be evaluated as a supplied feedback.

3.3.3 Generative design

Generative design can often be demonstrated and interpreted as a rule-based method of design, in which several promising design outcomes can be created. Rules in the generative design include parameters and variables. To produce a considerable and satisfactory design outcome, the parameters are applied in an organised manner. It is possible to understand the complex interaction between design features, climate, occupants, the mechanical and electrical system by only resorting to simulation fully. Moreover using simulation tools lead to engaging in design practice based on feedback loops between design decision and simulation impacts.

These simulations are introduced for creating relationships, between mathematical equations and different design tool in the algorithms. Then they are tested and evaluated to make design decisions. Nevertheless, this is a time-consuming and tedious process. Moreover, only a few steps can be evaluated among large possible choices. However, this method is not accurate because the designers are only able to choose a limited number of steps to simulate and evaluate. To have an accurate method, broader design ground should be considered along with the identification and application of basic design rules.

3.4 Rhinoceros/Grasshopper

As in previous sections, the importance of parametric modelling and simulation processes has been explained. It depends on Rhinoceros design software working as the primary platform with the help of Grasshopper parametric plugin. (Davidson (2013), http://www.grasshopper3d.com/) Said "Grasshopper requires no knowledge of programming or scripting, but still allows designers to build form generators from the simple to the awe-inspiring". Further, these tools are explained with more details.

3.4.1 Parametric and generative modelling in Rhino/Grasshopper

Grasshopper is an innovative parametric modelling tool. It is a module of Rhinoceros. Grasshopper is a persuasive design tool that permits to explore new dimensions of design. With this tool, one can modify the whole model without re-drawing or editing any parts of it, unlike other design software platforms. In this software, one does not need any prior familiarity with any scripting programming languages, as here geometries are drawn using graphical user interface. The geometry can be shaped by dragging and dropping accessible grasshopper tools. These tools are not only used for drawing, but they are also used for setting up the relationships between the geometries. As it is discussed in previous sections of this chapter, that "parameters" and "components" are two main types of objects in Grasshopper. Parameters are used as input variables for the components that modify the geometry of the design to generate the output.

The research methodology involved in describing how to achieve the research objective and its subtasks. Table 3.1 depicts the list of tools and technologies that are expected to be used at various phases, mentioned along with the achievable objects and the tasks involved in it.

3.5 Output of the algorithm

The output of the algorithm provides a new methodology, which helps to suggest new probable design models by implementing basic design rules to implement aesthetic elements and ergonomic anthropometric data. The algorithm will affect the following criteria of the new concept design as output:

- Overall Geometry – space, dimensions, organisation
- Customer appeal – shape, colour, texture, form, feel, smell, surprise and delight features
- User needs – type of operation, instructions, warnings
- Ergonomic design – man-machine relationships, operation, height, layout, comfort, lighting, interactions

3.6 Pseudo Algorithm

The figure shows the step by step methodological approach for explaining the functioning of the algorithm. Initially, the algorithm is divided into two parts according to their nature of the working process manual and automatic. Some areas of the algorithm are manual because Grasshopper doesn't have any image processing module. Therefore, the contouring part of the algorithm has to be done manually. Apart from that, all geometrical relations can be obtained automatically to obtain the following processes.

Manual process

1. **Procedure to obtain the basic form of the product:**
- Import image to Rhino
- Determining the contour lines of the image
- Allocate the outer surface while avoiding the inner and other textured surface lines

Automatic process

1. **Procedure to obtain the basic form of the product:**
- Exploding the lines in grasshopper and applying the Golden ratio to lines
- Determination of central axis according to the counter lines
- Plotting corresponding points to regenerate product volume
- Selection of the operation to obtain basic form like revolve, extrusion, scale, Sweep etc.

2. **Define proportion of the product**
- apply as much golden ratio relations without changing its fundamental form.
- Arguments provided to apply Gestalt Principles

3. **Anthropometric design procedure**
- Creating gripping surfaces and other ergonomic design requirements, according to hand anthropometric data

4. **Define texture of the product**
- Different surfaces with different purpose like artistic, functioning and ergonomic surfaces are provided in the algorithmwith easy manipuable forms, position, size and quantity

5. **Defining color of the product**
- Applying color properties and arguments as per masculine/ feminine preferences

6. **Manufacturing considerations**
- Manufacturing data like draft angle, minimal corner radius, finishing texture, arguments are provided

Figure 3.1 Working of the algorithm with Rhino and Grasshopper

3.6.1 Defining the basic form of the product from the image

First the initial image of the product is imported into the Rhino CAD environment as a two-dimensional element. Then a line is drawn manually to contour the image. There are no image processing features present in Grasshopper and that's why this has to be done manually in Rhino CAD interface. Then the contour lines were imported into Grasshopper interface as a BREP (a collection of connected line elements). As shown in Figure 3.1, the contour lines first automatically generate middle lines according to the product's shape. Then the extra part of the contour line is trimmed by central lines so that overlapping of the surface can be avoided. Otherwise, this overlapping of surface/lines can, later on, lead to open breaped (composition of multiple surfaces) surfaces that will create problems in algorithm execution.

The product thickness is then defined by doing an offset line. Then the whole trimmed line is revolved making the middle axis constant according to the form of the product. Moreover, the thickness of the container is defined as a flexible parameter. The revolving axis or central axis selection depends on the type of view that was given as input to the algorithm. In this way, the basic form of the product can be obtained.

3.6.2 Implication of anthropometric data

Once the basic form of the object is obtained, at first, all the ergonomic criteria have to be listed. Those principles are applied later on in the algorithm by including the anthropometric data. To implement anthropometric data, relations between different geometries have to be made. The changes in geometries will affect the form of the product so that the product will appeal to target group of customers with its enhanced usability. While applying ergonomic criteria to the algorithm, the product can be designed according to the gender, age, place, and cultural preferences.

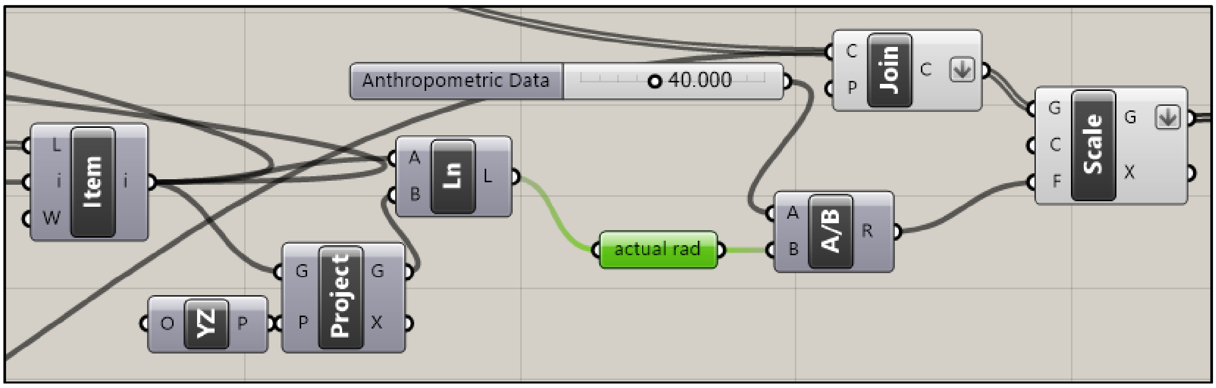


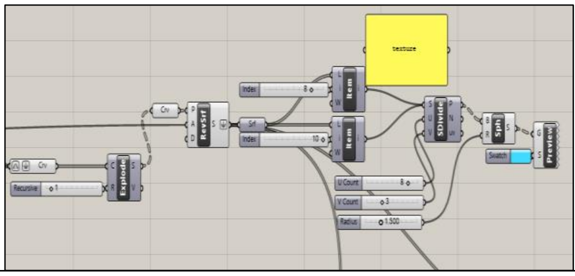
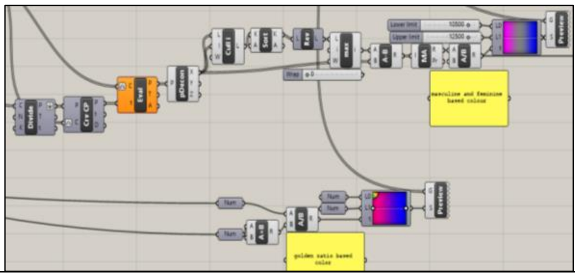
Figure 3.2 Application of the anthropometric data in the algorithm

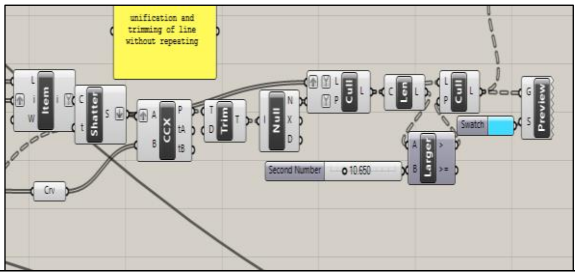
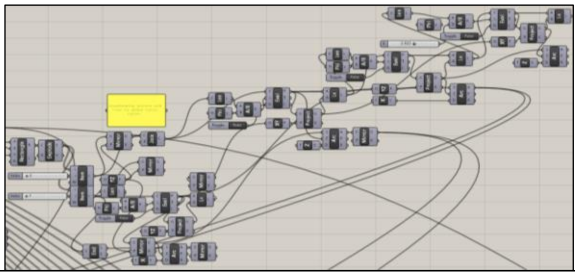
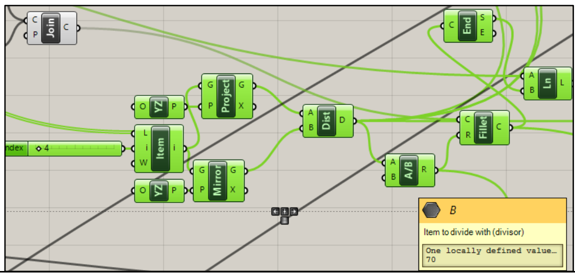
From Figure 3.2 the application of anthropometric data is used to modify the geometrical form of the object. In the algorithm, anthropometric data is used as a variable that is easy to adjust after the algorithm is completed. The algorithm is also very easily adaptable for similar kind of products. Mathematical relations established between various anthropometric data can be used to modify the basic form to increase product's usability.

3.6.3 Modification in its aesthetics properties

Product's aesthetics is divided into four components form, texture, colour and proportion. These parameters are decided on the basis of human sensors. Therefore, the introduction of aesthetics properties in a product is most crucial and challenging task. To enhance the aesthetic properties of a product, first the problems need to be understood in applying aesthetics in the algorithm. The problems to implement aesthetics in a product are discussed in the previous chapter. The main conclusive reason is the definition of beauty varies from person to person, and it's also difficult to quantify beauty or attractiveness. Table 3.2 shows the different part of the algorithm that helped to improve the aesthetics properties of the product model

Table 3.1 Aesthetic properties of the product model

Sl. No.	**Parts of the Algorithm to Apply Aesthetics**	**Explanation About the Corresponding Pictures to Improve Aesthetics Implications in the Algorithm**
1		Textural part of the algorithm to obtain desirable texture on any surface of the product's form.
2		Colour part of the algorithm as per gender specification and curviness of the lines.
3		Algorithm to trim all the untrimmed lines without repeating to obtain the form.

		
4		Part of the algorithm to transfer points and lines to golden curve.
5		Algorithm to identify and apply the fillet radius as per manufacturing standard for particular kind of products.

From Table 3.1 it can be identified those algorithms consist of 5 basic modules as per their unique functioning capabilities. Each part need some input to be supplied with their specific targeted output, to make modification in the simulating model. This process is done manually with the help of the sketch first. After that, the idea has to be transformed to the new model. Once the anthropometric data is applied to the algorithm all the fundamental modules that can be seen in Table 3.1, are applied with the help of the variables (supplied links).

3.7 Summary

In this chapter, the algorithm along with its methodological details are explained. Apart from that, the tools used are presented. The effective output of the algorithm with its detailed steps are discussed. From the above study, it is summarised that there is one subject required for the experimentation of the algorithm to check its usefulness.

Chapter 4

DESIGN MODIFICATION OF THE BOTTLE USING ERGONOMIC DATA

4.1 Overview

In this section, the focus of the case study is done with the help of a simple bottle and efforts are given to make the bottle more than a fluid container. An algorithm is developed by following combined strategy of core design rules and design art effects (like the golden ratio, ergonomic norms and Gestalt Theory, etc.). Furthermore, a new technique is proposed, that will help designers to make judgements at the concept design stage, by integrating parametric features and simulation tools together. The model has been implemented to Rhinoceros with a plug-in called Grasshopper, which will permit the user to work on individual variables parametrically.

Additionally, ergonomic and aesthetic properties of the bottle are enhanced by considering "anthropometric data" and "elements of aesthetics" to get a concept of the bottle. Rhinoceros and Grasshopper are linked to ensure a new design method, which can be able to provide immediate and easy modification of the bottle concept design. A case study has been defined to demonstrate the potential of the developing system, to manage the simulation and evolution of the bottle model during the conceptual design stage. Design decision values (Basic design rules) and anthropometric parameters are taken as the input values for the analysis model. And the improved aesthetics and ergonomics corresponding values of appearance will be returned as an output.

4.2 Steps of the algorithm to apply on the subject

As it is explained earlier, the Grasshopper software is used for parametric modelling. This software is very popular in the sector of architecture. First Portugal et al. (2012) implemented Grasshopper Rhino interface in a case study. They also tried to simplify the concept design phase by making easier design decisive phase for the designer. Since then the parametric and generative design got a lot of popularity and due to its open source, the development of this platform is rapidly increasing.

The model is applied to Rhinoceros with a plug-in called Grasshopper which permits the user to work on each variable parametrically. Besides that, the integration of Rhinoceros and Grasshopper provide a new platform that can offer superior design feedback in product design. A case study has been introduced to explain the possible functioning of the developed algorithm with the help of simulation and parametric modelling of a CAD product model during the conceptual design stage.

This algorithm starts with importing a product image into Rhinoceros design software. The next step is to determine the outer border line of the image. Only these two procedures are manual because there are no functions present in Grasshopper for image processing. From Fig. 3.1 the steps in methodology can be identified after determining the outer line of the product's image, the newly developed lines contain the design genes of previous products, in which the basic design rule, have to be incorporated. The next step is to create a simulation model of the product in Rhinoceros from the line that contains the product genes.

Then, the new contour line is bisected and trimmed to obtain a line according to its central axis by a centre line. Exploded line is sectioned into the several segments according to the line's properties when the line changes angle or turns or make a radius. These line segments are the inputs to applying basic design rules for converting, height and diameter ratio according to "golden ratio" with a corresponding transfer of points into new coordinates.

Plotting the respective points and making an offset of the newly formed line, is used as input to create the basic form of the product. On that form, the basic design rules are applied. The methodological details are shown in Figure 3.1. Out of two offset lines, a surface is made and trimmed to generate a breped surface in order to avoid complication to generate simulating product form. Revolving the whole surface around centre line makes a simulating form whose surface is divided later into sub-surfaces for introducing design rules.

To divide the surface, in "golden ratio" a curve has to be plot first on the subsurface. From there two surfaces are developed on which texture of the gripping surface is going to plot. The diameter of the gripping surface is set as per anthropometric data according to gender and place preferences. Then arrays of points are plotted on those gripping surfaces that will form small textural projections of form. The colour of the object will be determined from the colour cube. The colour of the object will change automatically according to its shape. More feminine (organic) product will acquire colours towards pink and more geometric form will acquire the colour towards blue to reflect the property of female and male preferences respectively.

In the algorithm, a set of parameters and variables has been defined to state a new design in Grasshopper. These parameters and variables are the bases of genetic elements of design, which can identify the design with its constituents like aesthetics and ergonomics. The design variables are designed features that manipulate the design elements to find the best possible solution in the design evaluation.

4.3 Detailed design

This algorithm not only considered product language and functions during concept designing phase but also products aesthetic and ergonomic properties are considered in the prototype. The aesthetic is all about observing through human senses, therefore it has been categorized in four different areas based on specific elements. The discussed algorithm has four different segments which explain the aesthetic properties of the object such as form, colour, texture and proportion. Similarly during the phase of concept design different models have been proposed using ergonomic factors. All the tabular factors and figures considered for the individual steps are explained at the bottom of the each steps.

4.3.1 Form point of view

In this algorithm, the image is imported into the Rhinoceros software as input. Image may be the bottle or any another image whose aesthetic properties have to be incorporated. Applying algorithm will change its other aesthetic properties, keeping its form properties constant. Form of a product can be manipulated in a lot of ways. From Ehrnberger, et al. (2012) work it could be understood that female prefers more fluidic, naturalistic product form and male community prefer more geometric and abstract product form. Simultaneously it also explained how muscular and feminine product forms of a similar type of product have psychological superiority over one another.

In this algorithm, whether the product is more feminine or masculine the logic depends upon its height and width of the product. The curviness of the surfaces also creates an impact on products masculine and feminine property. It is considered that the straightness of the surface reflects geometric property due to its closeness to basic geometric shapes hence it leads to more male-oriented design approach. Similarly the opposite is true for more female oriented design approach.

Table 4.1 Factors considered for form manipulation

Factors	Remarks
Height	It affects the masculine or famine nature of the object form directly
Width of product	It also affects the masculine or famine nature of the object form directly
Curviness of the surface	To determine masculine and feminine level with comparison of it with a straight surface
Centre line of the product	To determine revolving surface around product

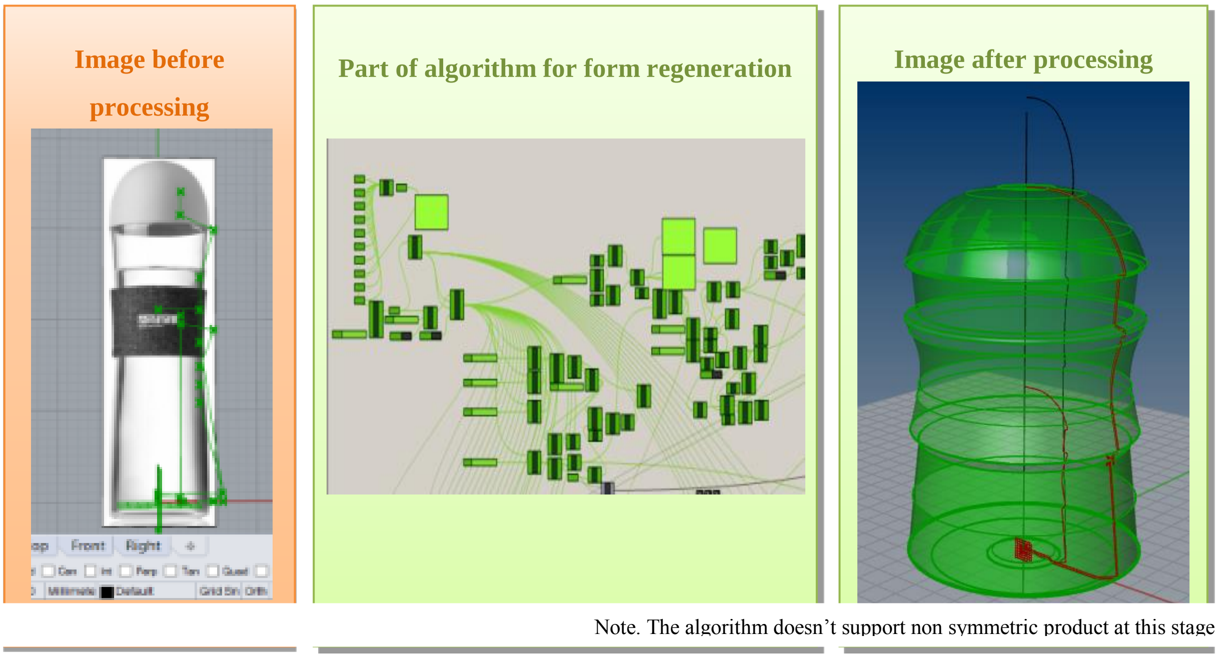


Figure 4.1 Process for product's form regeneration from an input image

4.3.2 Colour point of view

The algorithm colours the product according to its form and male, female preferences. (Fenko et al. (2014) and Ehrenberger et al. (2012)) Studies have been applied to the algorithm to colour the product. According to the Ehrenberger et al. (2012), more male-oriented designed products have straight or flat surfaces that are closer to basic geometric forms. On the other hand, according to Fenko et al. (2014), more famine product's colour should be close to pink and similarly blue colour suggested for masculine oriented designs.

Above described idea is imported and applied in the algorithm and product's colour is modified according to the magnitude of male and female properties of the targeted product. As it is known grasshopper is parametric programming and its quite easy to very its ratio. It is observed that when the ratio of the overall height and width of the product is in the golden ratio, the colour of the product is grey. And grey as a neutral, earth toned colour has no gender appeal. Thus, it could be assumed that golden ratio favours unisex parameters. And unisex parameters are often excluded using gendered colours, shapes, and attributes so that the outcome won't have a solid identity.

Hence two prime elements considered to control colour are golden ratio and the acquired product form. Again golden ratio is controlled by height-width ratios of the concepts, along with some other useful golden ratio relations that have been discussed in the work earlier. These two criteria might be employed till more functional criteria like ergonomics and manufacturing are adversely affected.

The form acquired from image is derived after considerations of anthropometry. That is, the idea of the algorithm is to maintain the basic form characteristics from the image but additionally anthropometric data is included in the process to find a customized design solution. As a result, when the prototype is present in its gender targeted form along with correct anthropometric data, it might also appear in colours such as grey or green (and not just the extremes, i.e. blue and pink) indicating that the product is not in golden ratio or that other golden ratio relations can be establish. Similarly the prototype might appear in the same grey or green when there exist a golden ratio condition with no anthropometric data inputs. In this way, visualizers can be made aware of refined concept designs using multiple design criteria like aesthetics and ergonomics.

Table 4.2 Factors considered for colour manipulation

Factors	Remarks
Form of the product	It’s used as input to the geometry to preview the object
Initial curve drew manually	It helps in determining parameter in gradient range
Surface of the object	To define masculine and feminine property of the surface with comparisons of it to a plane surface
Height to width ratio	Because it directly affects the basic form of object

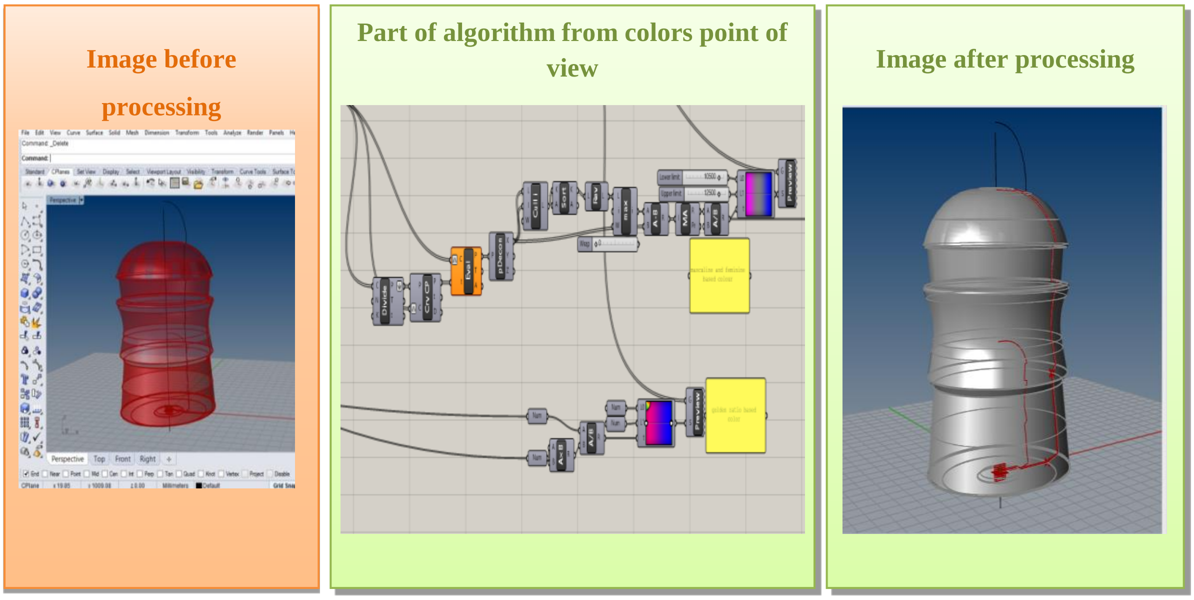


Figure 4.2 Process for product colour calculating

4.3.3 Texture point of view

In this algorithm, the gripping part of the bottle is textured with a series of small sphere whose that shape, position and quantity can be modified according to the bottle dimension. Even these forms can be replaced by any other textural forms with no redesigning time delays. The gripping surface diameter is decided from the anthropometric data of human hand.

Table 4.3 Factors considered for texture manipulation

Factors	Remarks
Gripping curve from image	This curve has to be obtained manually
Shape of the textural surface	In this case its small spear
Arrangements of textural element with help of Gestalt theory	continuation, closure, proximity and symmetry
Anthropometric data of human hand width	To determine the width of the gripping surface
Anthropometric data of human thumb	To determine the type of grip
Anthropometric data of human index finger	To determine actual gripping surface
Anthropometric data of space between human index finger and thumb.	To determine actual gripping surface

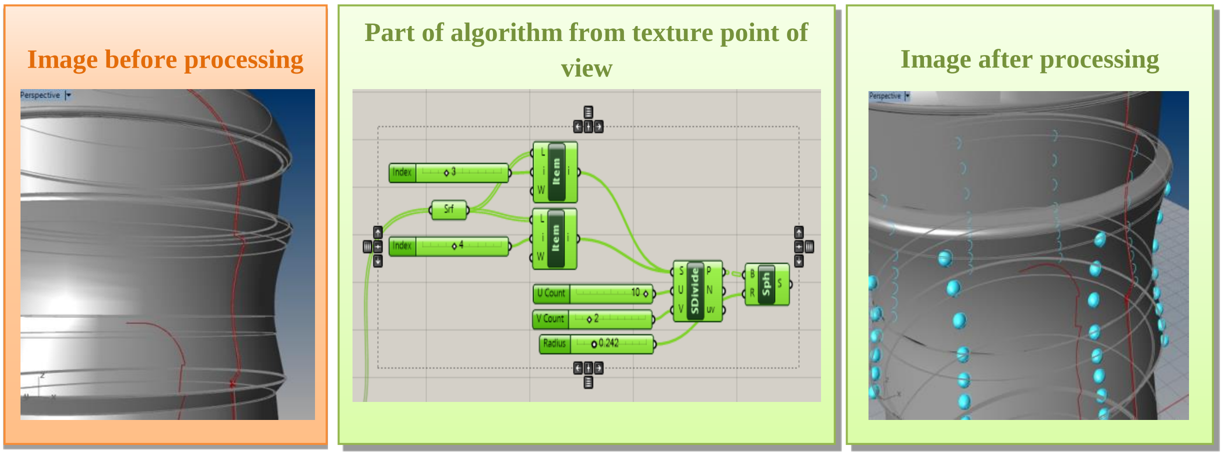


Figure 4.3 The picture of bottle with texture algorithm

4.3.4 Proportion point of view

This algorithm converts the whole height and width ratio into the “golden ratio”. The ratio can also be changed according to our masculine and feminine need. In fact, it’s the basic way to make a product more masculine and feminine according to the target audience. This algorithm, it also divides the gripping surface according to the “golden ratio” in relation to the whole object. The idea was to make as much golden ratio relations as possible without violating its basic form.

Table 4.4 Factors considered for proportion calculation

Factors	Remarks
Exploded index of subdivided lines	For identifying implementation target
Anthropometric data of hand width without thumb	
Anthropometric data of Gripping circumference	
Length of Index finger	To get actual dimension of the product
Length of the thumb	
Distance between bottom of index and thumb	
Height and width of the object	For the golden ratio
Identifying Lines close to logarithmic curve	Transformation of nearest lines to logarithmic curve

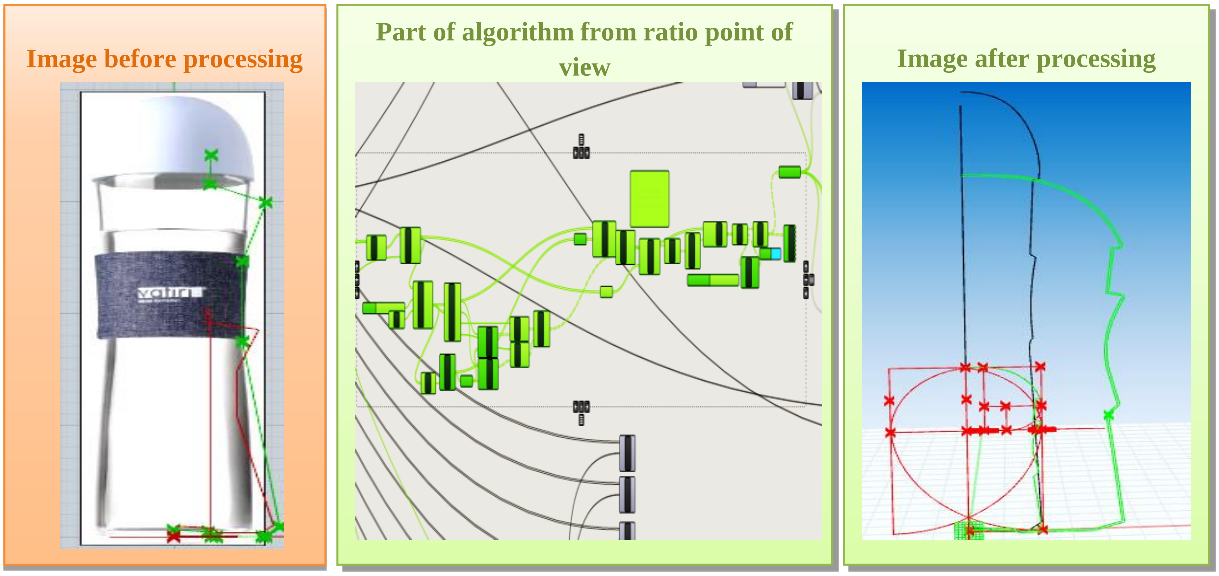


Figure 4.4 Process for proportion product calculating

4.4 Manufacturing part

The bottle manufacturing is done by blow moulding process. To design a product according to the manufacturing conditions, manufacturing data like draft angle, minimal corner radius, finishing texture, etc. has to be considered. Due to the current advances in manufacturing processes most of the manufacturing conditions is achieved by die design. And the priority of the design suggestion provided by algorithm shouldn't be violated by the current manufacturing process.

From the figure it can be seen that the fillet radius is calculated from a ratio, it means it is not fixed. Minimal cornering radius is controlled by the ratio of the radius of the bottle and a constant so that it should depend on the size of the bottle. A constraint is provided that the minimal corner radius should not be less than 3.175mm in any condition so that sharp 90^0 corner can be avoided, which might result in thin and weak edges.

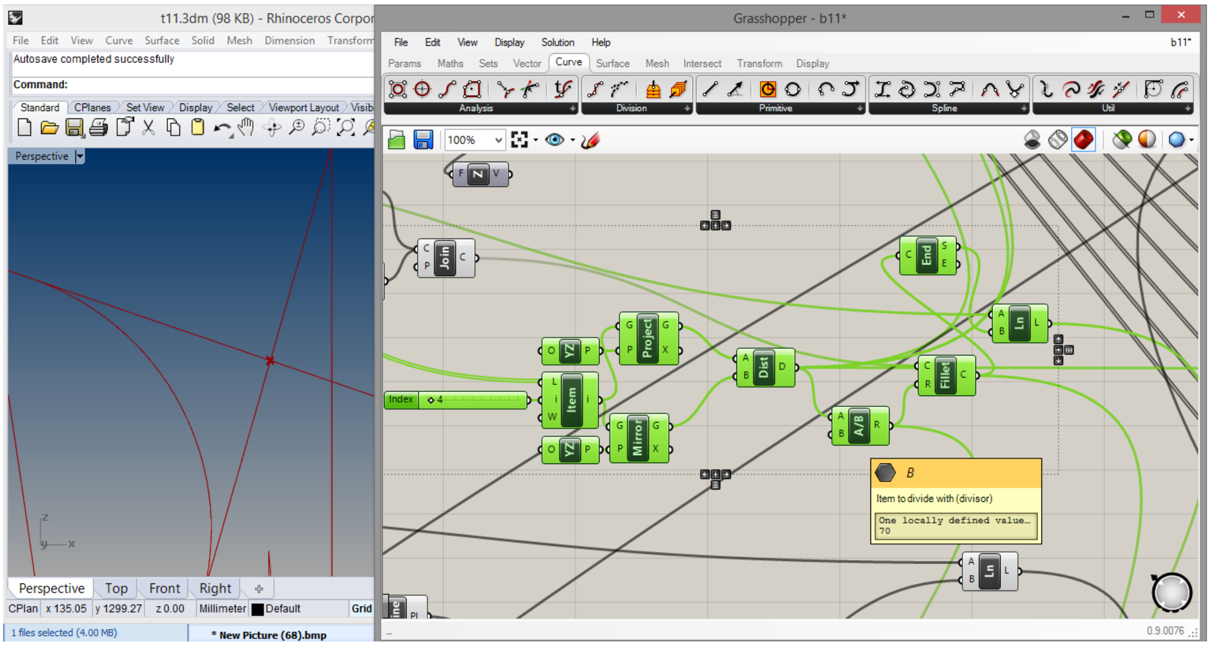


Figure 4.5 Minimal cornering radius applications in the algorithms.

Note. The manufacturing data considered from Engineering Polymers Part and Mould Design Thermoplastics data book.

Apart from that, this above algorithm also uses Gestalt Theory. There are six common, basic Gestalt Principles continuation, closure, proximity, figure/ground, and symmetry and in this algorithm it is successfully implemented in several places.

4.5 Summary

In this Master's thesis a subject was selected, to test the above-explained methods and theories. This subject will reveal the advantages and drawbacks of the designed algorithm in the simulating environment. And it will highlight the gap between existing research work and actual practice. It will help in justifying the reason to meet the design standards of a specimen. In this chapter, approaches adapted for modifying the bottle are justified through different steps. Consequently, it is summarised that there is a need to explore the development process further.

Chapter 5

RESULT AND DISCUSSION

5.1 Overview

The impact of aesthetics and ergonomics on customer purchasing choices, can't be undervalued. The focus of the product design is almost always concentrated on functional requirements of the product. In generally, other aspects like ergonomics, aesthetics and usability are not considered.

Helander (2003) findings seem to support the results of this study where the perception of ergonomics and usability is weakly related to aesthetics. Furthermore, consumer's perception of ergonomics and usability directly depend on the consumer's prior knowledge of ergonomics and usability. But even then assessing the perception of ergonomics and usability may be a difficult task. Without holding or handling the tool physically, consumers may not be able to distinguish ergonomic and usability features in the individual product.

5.2 Curve gender quantification solution

Forms can be brodly classified into geometic and organic (often curvy). Though there is an argument that sphere or circle also considered as geometric shape but Robert Lawlor, Sacred Geometry - Geometry of the Body wrote that "Every known life form begins as a sphere. It's the most female form there is, so it makes perfect sense that the female would choose that shape to form the ovum. The ovum is a sphere." Ehrnberger et al. (2012) highlighted a gender perspective design practice for two common household appliances with the application of deconstruction theory into new prototypes. The work is based on the logic of curviness often being perceived with feminity.

First, the contour line drawn out of image is divided into multiple segments according to its path modification. It means the segmented curve will always be a symmetric curve. To quantify a curve according to its masculine and feminine preference, a simple method was used by obtaining end points of the curve and draging the shortest line in between those points. Then taking that line as diameter, a half circle is made. The half circle is assumed as the female side and the straight line considered as the male side of the entire curve. And the distance between the middle point of the curve and the middle point of the line is considered as the input to the algorithm to modify other aesthetic elements.

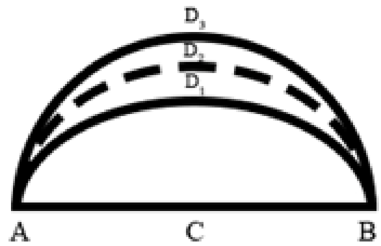


Figure 5.1 Diagram to evaluate curviness as per gender specification

Line AB = Straight line (assumed male curve)

Curve AD_1B = Arc of half circle (assumed as female curve)

Line CD_1, CD_2, CD_3 = Distance used as input to algorithm to quantify other aesthetic elements

Note: Before evaluating a whole curve the cumulative evaluation has to be performed after transforming all curves to same evaluating platform.`

$(CD_1 + CD_2 + CD_3 + ... + CD_n)/n = x$

Where n is the number of segment curves to evaluate and is the cumulative curviness of the whole spline. Later on all cumilative segments are used as inputs to the algorithm.

Note. This part of the algorithm receives input, after the gender-based evaluation of curve

5.3 Comparison of different design concepts with variation in aesthetic and ergonomic properties

To investigate the aesthetics and physical ergonomics a bottle was chosen. This product was selected because bottle is a highly visible product that people often invest in for both functional and aesthetic reasons and the form has significant ergonomic implications.

In the design process the dimensions of the product determine the anthropometric data applied. In the bottle under study dimensions of gripping circumference need to be determined from hand anthropometric data (Lehto et al. (2013), Legg et al. (2008), RoyMech et al. (2008)).

To determine the object dimension of *gripping circumference,* equation (5.1) has been defined:

$$Ag. = Ac / fg \ldots\ldots\ldots\ldots\ldots\ldots \quad (5.1)$$

Where

A_c: Anthropometric circumference

f_g: Gripping factor.w

w: Diameter of the bottle

A_g: Actual gripping circumference

Gripping factor is a term introduced by the auther that indicates the percentage of circum,ference a human hand is able to cover when holding the bottle. The factor is indipendendent of the gender of a person.

Similarly *Anthropometric circumference (Ac)* have been calculated from equation (5.2):

$$Ac = Li + Lt + Lit \ldots\ldots\ldots \quad (5.2)$$

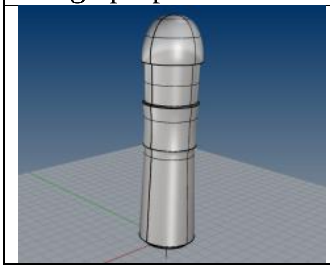
Where multi

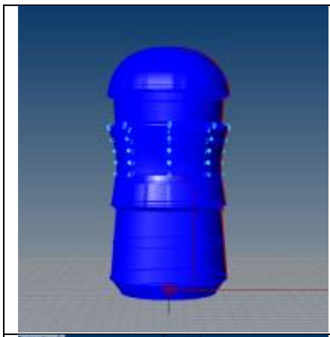
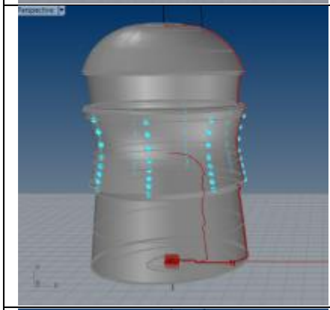
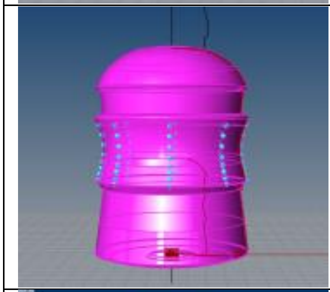
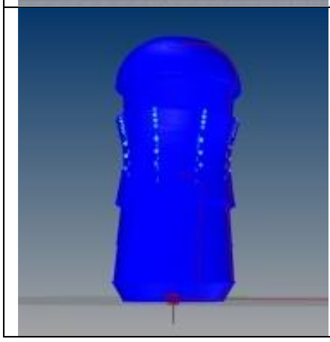
Li: Length of Index finger

Lt: Length of the thumb finger

Lit: Distance between bottom of both index and thumb

Table 5.1 Comparison and analysis of the same bottle with different factors

Algorithm product design proposal	Factors included to run algorithm
	Bottle as its original form Here the form is imported from an image so it's not having actual dimensions of the object. No anthropometric data and aesthetic values are applied in this from

	Bottle with male anthropometric data with golden ratio PARAMETERS VALUES APPLIED Height of the bottle (h) = 129 Diameter of the bottle (w) = 80 Anthropometric circumference for median50% male (A_c) = 75((Li) + 51(Lt) +50 (Lit) = 176 Gripping factor (f) = .7 Actual Circumference (A) = 251
	Bottle designed as per golden ratio only PARAMETERS VALUES APPLIED Height of the bottle (h) Diameter of the bottle (w) Centre of gripping surface from ground (d) Golden ratio applied = h/w, h/d,
	Bottle with female anthropometric data with golden ratio PARAMETERS VALUES APPLIED Height of the bottle (h) = 117 Diameter of the bottle (w) = 73 Anthropometric circumference for median50% female (A_c) = 69(Li) + 47(Lt) +45 (Lit) = 161 Gripping factor (f) = .7 Actual Circumference (A) = 230
	Bottle with female anthropometric data without golden ratio PARAMETERS VALUES APPLIED Height of the bottle (h) = As required Diameter of the bottle (w) = 73 Anthropometric circumference for median50% female (A_c) = 69(Li) + 47(Lt) +45 (Lit) = 161 Gripping factor (f) = .7 Actual Circumference (A) = 230
	Bottle with male anthropometric data without golden ratio PARAMETERS VALUES APPLIED Height of the bottle (h) = As required Diameter of the bottle (w) = 80 Anthropometric circumference for median50% male (A_c) = 75(Li) + 51(Lt) +50 (Lit) = 176 Gripping factor (f) = .7 Actual Circumference (A) = 251

Hand Anthropometry of non-disabled individuals (Legg et al. (2008), RoyMech et al. (2008))

In Table 5.1, six different types of product configuration have been shown. All of the products shown have different aesthetics and ergonomic details. In the algorithm, changes are made in the variables to manipulate the aesthetic elements with the help of ergonomic anthropometric data. Out of six types of product specimen, the factor considered for aesthetics manipulation varies with the height and diameter ratio, anthropometric hand data according to male-female details, 2D curve's curviness and colour details, etc.

This algorithm not only considered product language and functions during concept designing phase but also product's aesthetics and ergonomics properties are considered in the prototype. Aesthetics is all about observing through human senses. For that reason it is divided into four basic elements. Therefore the algorithm has four parts that depend on the aesthetic property to design object: form, colour, texture and proportion. The same way several models have been proposed using ergonomic factors during concept design phase.

5.4 Discussion

In this algorithm, the image is imported into Rhino designing software as input. The picture may be of the bottle or some other whose aesthetic properties are to be incorporated. Applying algorithm will change its other aesthetic properties, keeping its form properties constant. From of a product can be manipulated in a lot of ways. From Ehrnberger, et al. (2012) work it could be understood that female prefers more fluidic, naturalistic product form and male community prefer more geometric and abstract product form. Simultaneously it also explained how muscular and feminine product forms of a similar type of product have psychological superiority over one another.

On the other hand, consumers with ergonomic knowledge may be more particular when purchasing hand tools. Although, there is no connection between perceived ergonomics, usability and aesthetics as demonstrated in this study, good ergonomics is a prerequisite for a sense of well-being, relief and satisfaction (Helander, 2003). Products with excellent visual appeal, but with poor ergonomics and usability will ultimately suffer in the long run. The solution is to integrate ergonomics, usability and aesthetics into one package for the future success of any product in the marketplace.

From the standard household appliance to highly sophisticated machinery, aesthetics remains to be of an utmost importance. Norman (2002) pointed out that the importance of aesthetics has outgrown the importance of usability. In the field of usability, a significant correlation is noted between beauty and usability. According to the phenomenon of social psychology what is beautiful is good (Hassenzahl (2004); Tractinsky et al., (2000)). Tractinsky's study demonstrated a relationship between aesthetics and usability. Intuitively, one would generalise the findings of Tractinsky into hand tools.

So here in this algorithm it is considered that, a product's feminine or masculine logic depends upon the height and width of the product. The curviness of the surfaces also create an impact on products masculine and feminine property. The straightness of the surface reflects geometric property due to its closeness to basic geometric shapes hence it leads to more male-oriented designs. Similarly the opposite is for more female oriented designs.

5.5 Summary

In this chapter, first the different concepts of the bottles are compared with respect to their aesthetic and ergonomic details. And to obtain the result, an image is presented to evaluate and evaluate the curviness as per gender specification in the algorithm. Finally the results and the effects of the results are discussed to prove the worthiness of the algorithm.

Chapter 6

CONCLUSION AND FUTURE WORK

6.1 Overview

At the beginning of this research, one major problem had been identified, in the product evaluation process by psychological surveys of people. More often these results don't have any fixed output. It varies rapidly with different factors like age, sex, culture, time, personality, etc. This work discovered difficulties in product design and looks forward at applying basic design rules in the field of concept design with the help of Grasshopper design module. In this problem, a semi-automated process is introduced through an algorithm to implement ergonomics and aesthetics. Especially for product design based on Grasshopper (graphical algorithm editor tightly integrated with Rhino's 3-D modelling tools). This algorithm is based on applying basic design theory like stability, rhythm, balance, organization, golden ratio, etc. Although there are several design ideas present, they are not applied in current design practices. So in the present research, the focus is laid on automation and implication of basic design theories. Psychological evaluation of products doesn't give fixed outputs with stable results. Finally, this work presented a case study of designing a bottle with the help of this algorithm.

6.2 Conclusion

In this research, the value of aesthetics appearance and ergonomic norms is reconsidered in the field of product design with the aid of an algorithm. Aesthetics was broken into its essential elements like form, colour, texture and proportion. A product image was introduced as an input to the algorithm. Ergonomic anthropometric data was also applied as per target specific design process. The aim of the algorithm is to exclude the user's evaluation process during concept design phase and to bring the automation in the field of product concept design.

The algorithm provided ground to operate and explore the automation of design process during concept design phase. But maybe it's a little less appropriate to use it in a real-life situation, because for every class of product a different algorithm might be applicable. Once the algorithm is complete for one category of product, it’s very useful to adopt and manipulate it for similar class of products which will save a lot of time during the introduction of aesthetic and ergonomic factors in a design process.

From this work, it’s hypothesised that the algorithm successfully includes aesthetic and ergonomic functions in a prototype. The introduction of algorithm introduces automation in the concept design phase that saves a lot of time for the similar class of products. The current process also reduces the use of traditional sketching process to transfer topological values to the design. From different simulating models, the functionality of the new product can be examined easily.

It is expected that from this new design process, there will be automation in the phase of concept design. Design evaluations will be conducted in more open and correct ways. As per recent developments in algorithms and computer programmes, it is assumed that soon artificial intelligence will be included in the field of product design. The algorithm is still a research prototype, and as such, a subject of intensive development, especially the most subjective part of the system dealing with engineering aesthetics and aesthetic ergonomics.

6.3 The novelty of the work

- As discussed previously in methodology chapter, aesthetic and ergonomic factors are divided into four different criteria to make changes in the newly designed product. In the algorithm, the input to the algorithm is an image file and output is a CAD model.
- In our case study, except product form other aesthetic properties are covered like colour, texture, proportion because the product image is given as an input to the algorithm. This reflects the primary criterion for the initial stage of design. The primary goal of the algorithm to eliminate the user’s uncertain psychological evaluations, during concept design phase. This problem provide us the opportunity to investigate the role of aesthetics in designing evaluation. A unique way is presented to bring the automation in the field of product aesthetic evaluation, using basic design rules for example stability, rhythm, balance, organization, golden ratio etc .

- The authors believe that the designs resulting from this approach are innovative and invite automation in the concept design phase that saves a lot of time. It has been hypothesized that the algorithm will be a success in attaining this outcome. As in any design process, the techniques used inspires the outcome. It is unlikely that basic design theories could not be achieved by using a traditional technique like sketching.
- The bottle would need to be improved in design optimisation before being ready to use in real life context. It's concluded that the presented design approach in this research should not be seen as a finished design process, in case designing products for the market is the goal, but it can be a useful part of a larger process of innovation.

6.4 Problem analysis via its solution

The resulting designs of the case study are research prototypes. The algorithm proved their use as vehicles for exploring, how to automate the design during concept design phase. But this approach may be less suitable for use in a real-life context because each class of product that has to be developed a new algorithm is required. But once the algorithm is complete it’s very useful to be adopted for similar type of products which will save a lot of time during aesthetic and ergonomic implication in a design.

6.5 Contribution of the research work

The contributions of this thesis in light of above summary and findings have been discussed as follows:

A new method for product design is developed with proof of its completeness and correctness. Most of the papers studied during the literature survey are related to form and colour in aesthetic design. But, there are several other factors to be considered in aesthetic designs. As far as ergonomic design is concern it is mostly software based and integration of both aesthetic end ergonomic design will bring a new era in design history. Product will be classed not only on the basis of manufacturing but also on the basis of the design culture. Product will be truly accepted in society not only physically but also psychologically.

6.6 Future work

Future research in this area could focus on the development of the algorithm, to grow its ability for producing answers to the problem of integrating aesthetics and ergonomics in design. In this research, some methods have been suggested for the investigation of the bottle. Moreover, the use of the algorithm proposed by the designers will provide feedback on its use that will make this tool more flexible and adequate to particular cases.

This research work seeks to expand the knowledge and understanding of aesthetics and ergonomics in the field of design. Though today, there are methods to incorporate aesthetics and ergonomics in design process but still there is a large gap between developed and developing nations when consuming products. This gap is still considered as a burden in the design process. The aesthetic evaluation procedures also lack in providing certain and concrete results. Therefore, automation is required in this blurred model of concept design phase. New design algorithm for a bottle was tested successfully. To make this algorithm adaptable for all products, deeper and extensive research is required. This might lead to standardisation in the field of design.

Another important concideration for future work is in terms of Design for X (design for reliability, design for manufacture, design for servicibility, etc.). There is also a need to determine if the layer for asthetics and ergonomics need to be considered on the product before or after DFX.

Therefore, this work provides a window of opportunity to implement automation in the concept design phase and it can be achieved by strengthening research collaboration, and raising international status of both the universities. This will offer a reliable research framework to implement automation and to reduce design failure risks.

In the future, additional case studies to serve the purpose of algorithm validation would help strenghtening this process further. Further research in user evaluation is also planned from algorithm 2D virtual solutions to 3D physical prototypes. Those prototyped will be printed and evaluated for users in order to determine if designs criteria align with the user opinions about the product.

Reference:

Aarts E., Marzano S. (2003). “The new every day. Views on ambient intelligence”. Rotterdam: 010 Publishers.

Asensio-Cuesta S., Diego-Mas J.A., Cremades-Oliver L.V., González-Cruz M.C. (2012). A method to design job rotation schedules to prevent work-related musculoskeletal disorders in repetitive work. International Journal of Production Research, 12(1)

Bertelsen O.W., Pold S. (2004). Criticism as an Approach to Interface Aesthetics. Proceedings of the third Nordic conference on Human-computer interaction, pp 23-32

Cai D.,You M. (1998). An ergonomic approach to public squatting-type toilet design. Applied Ergonomics, 29(2), pp 147-153

Chalabee H. (2013). Performance-based architectural design: Optimisation of building opening generation using generative algorithms. Dissertation: school of architecture of the university of Sheffield

Christopher J.G., Matthew B.P. (2012). Optimization of product dimensions for discrete sizing applied to a tool handle. International Journal of Industrial Ergonomics, 42(1), pp 56–64

Cillo P., Verona G. (2008). Search Styles in Style Searching: Exploring Innovation Strategies in Fashion Firms. Long Range Planning, 41(6), pp 650–671

Clarkson J., Eckert C. Design Process Improvement. A review of current practice. Chapter: Design Process Improvement, pp 34-59

Demirbilek O., Sener B. (2003). Product design, semantics and emotional response. Ergonomics, 46, pp 13-14

DTI (2002). Consumer and Competition Policy Directorate: Specific Anthropometric and strength data for people with dexterity disability (URN 02/743). Department of Trade and Industry, London.

Du S., Wu Q., Wang Y., Yi Z. (2009). Study of Method for Computer Aided Ergonomics Knowledge Management and Design Aiming at Product Design. Computer-Aided Industrial Design & Conceptual Design, pp 1176-1180.

Ehrnberger K., Räsänen M., Ilstedt S. (2012).Visualising gender norms in design: Meet the mega hurricane mixer and the drill dolphia. International Journal of Design, 6(3), pp 85-98

Ergonomics for Schools. Hand Tools. Retrieved December 10, 2008 from http://www.ergonomics4schools.com/lzone/tools.htm

Feijs M.G., Kyffin S., Young B. (eds.). The 1st European workshop on Design and Semantics of Form and Movement, pp 23-55. Newcastle: Northumbria University

Fenko A., Drost W. (2014). “A study in pink: what determines the success of gender-specific advertising?”. Proceedings: 13th International Conferences on Research in Advertising (ICORIA), Amsterdam

Fenko A., Drost W. (2014). A study in pink: what determines the success of gender-specific advertising. 13th International Conferences on Research in Advertising (ICORIA), Amsterdam

Frens J.W. (2006). Designing for rich interaction: Integrating form, interaction and function. Eindhoven university of technology

Hackney P. (1998). Making connections (2nd ed.). New York: Routledge

Hassenzahl M. (2004). The Interplay of Beauty, Goodness, and Usability in Interactive Products. Human Computer Interaction, 19, pp 319–349

Helander M. (2003). Forget about ergonomics in chair design? Focus on aesthetics and comfort!. Ergonomics, 46, pp 13-14

Hertenstein J.H., Platt M.B., Veryzer R.W. (2005). The Impact of Industrial Design Effectiveness on Corporate Financial Performance. Product Innovation Management, 22, pp 3–21

Hsiao S.W., Chiu F.Y., Chen C.S. (2008). Applying aesthetics measurement to product design. International Journal of Industrial Ergonomics, 38 (11-12)

Hummels C.C.M., Djajadiningrat J.P., Overbeeke C.J. (2001). Knowing, doing and feeling: Communicating with your digital products. Proceedings: Interdisziplinäres Kolleg Kognitions - und Neurowissenschaften. Günneam Möhnesee, Germany: InterdisziplinäresKolleg, pp 289-308

Kaljun J., Dolšak B. (2012). Improving Products: Ergonomic Value Using Intelligent Decision Support System. Journal of Mechanical Engineering, 58(4), pp 271-280

Karkowski W., Genaidy A.M., Asfour S.S. (1990). Computer-Aided Ergonomics. Taylor & Francis, London.

Kelly J.C., Maheut P., Petiot J.-F., Papalambros P.Y. (2011). Incorporating user shape preference in engineering design optimisation. Journal of Engineering Design, 22, pp 627-650

Klooster S., Overbeeke C.J. (2005). Designing products as an integral part of choreography of interaction: The product’s form as an integral part of movement

Kluth K., Strasser H. (2006). Ergonomics in the rescue service—Ergonomic evaluation of ambulance cots. 36, pp 247–256

Kolarevic B. (ed.) (2003). Architecture in the Digital Age: Design and Manufacturing, Spon Press, London, UK

Kroemer K., Kroemer H., Kroemer-Elbert K. (2001). Ergonomics – How to design for ease and efficiency. Prentice Hall, New York

Laban R., Lawrence F.C. (1947). Effort (4th ed.). London: MacDonald & Evans

Lawlor R.. Sacred Geometry - Geometry of the Body, pp 30-46 (http://www.themeasuringsystemofthegods.com/index_files/Page383.htm)

Legg S., Karen J. (2008). Ergonomics for School. Work, 31(4), pp 489–493

Lehto M., Landry S.J. (2013). Introduction to Human Factors and Ergonomics for Engineers (2nd ed.). CRC Press, Taylor & Francis Group.

Lili G.L., Grewal R., Bowman D., Ding M., Griffin A., Kumar V., Das D.N., Peres R., Srinivasan R., Wang Q. (2010). Calculating, creating, and claiming value in business markets: Status and research agenda. Marketing Letters, 21(3), pp 287-299

Ling R. (2004). The mobile connection: The cell phone's impact on society. Morgan Kaufman Publishers, San Francisco

Liu Y. (2003). Engineering aesthetics and aesthetic ergonomics: Theoretical foundations and a dual-process research methodology. Ergonomics, 46(13-14), pp 1273-1292

Liu Y. (2003). Engineering aesthetics and aesthetic ergonomics: Theoretical foundations and a dual-process research methodology. Ergonomics, 46(13-14)

Liu Y. (2003). The aesthetic and the ethic dimensions of human factors and design. Ergonomics, 46(13-14), pp 1293-1305

Locher P., Overbeeke C. J., Wensveen S.A.G. (2010). Aesthetic interaction: A framework. Design Issues, 26(2), pp 70-79

Mahlke S., Lemke I., Thüring M. (2007). The Diversity of Non-instrumental Qualities in Human-Technology Interaction. MMI-Interaktiv, 13

Mallikarjnn K.S., Manas M. (2007). Design of Bicycle for Indian Children Focusing on Aesthetic and Ergonomics. SasTech, 6(1)

Munsell A.H. (1912). A Pigment Color System and Notation. The American Journal of Psychology, 23(2), pp 236–244

Nathan-Roberts D. (2012). Using Interactive Genetic Algorithms to Support Aesthetic Ergonomic Design. Dissertation: University of Michigan, Ann Arbor, Michigan

Nathan-Roberts D., Yili L. (2012). Integrating Aesthetic and Usability Factors in the Design of Mobile Phones. Proceedings: The Human Factors and Ergonomics Society, 56th Annual Meeting, pp 1962-1966

Norman D.A. (2002). Emotion and design: Attractive things work better. Interactions, 9(4), pp 36-42

Portugal V., Guedes M. (2012). 'Multi-Objective Façade Optimization For Daylighting Design Using a Genetic Algorithm'. PLEA 2012, Lima, Peru

Ross P.R., Wensveen, S.A.G. (2010). Designing Behavior in Interaction: Using Aesthetic Experience as a Mechanism for Design. International journal of design, 4(2), pp 3-13

RoyMech (2008). Anthropometric Notes. Retrieved http://www.roymech.co.uk/Useful_Tables/Human/Human_sizes.html

Shoshi B.E. (2013). Sketching profiles: Awareness to individual differences in sketching as a means of enhancing design solution development. Design Studies, 34(4)

Smith W.K., Lewis M.W. (2011). Towards a theory of paradox: a dynamic equilibrium model of organizing. Academy of Management Review, 36(2), 381–403

Tomiyama T., Gub P., Jind Y., Lutterse D., Kind C., Kimurag F. (2009). Design methodologies: Industrial and educational applications, CIRP Annals - Manufacturing Technology, 58(2), pp 543–565

Tractinsky N., Katz A.S., Ikar D. (2000). What is beautiful is usable. Interacting with Computers, 13, pp 127-145

Ulrich K.T. (2006). Aesthetics in design. Design: Creation of Artifacts in Society.

Utterback J.M., Vedin B.-A., Alvarez E., Ekman S., Sanderson S.W., Tether B., Verganti R. (2006). Design-inspired innovation. New York: World Scientific.

Wang Y., Wu D., Zhao M., Li J. (2014). Evaluation on an ergonomic design of functional clothing for wheelchair users. Applied Ergonomics, 45, pp 550-555

Wucies W. (1972). Principle of Two-Dimensional Design. John Wiley & Sons